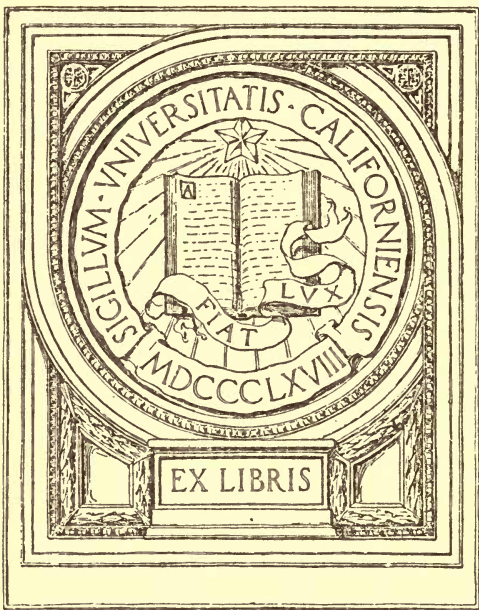


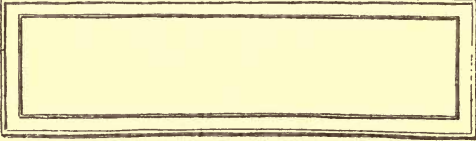
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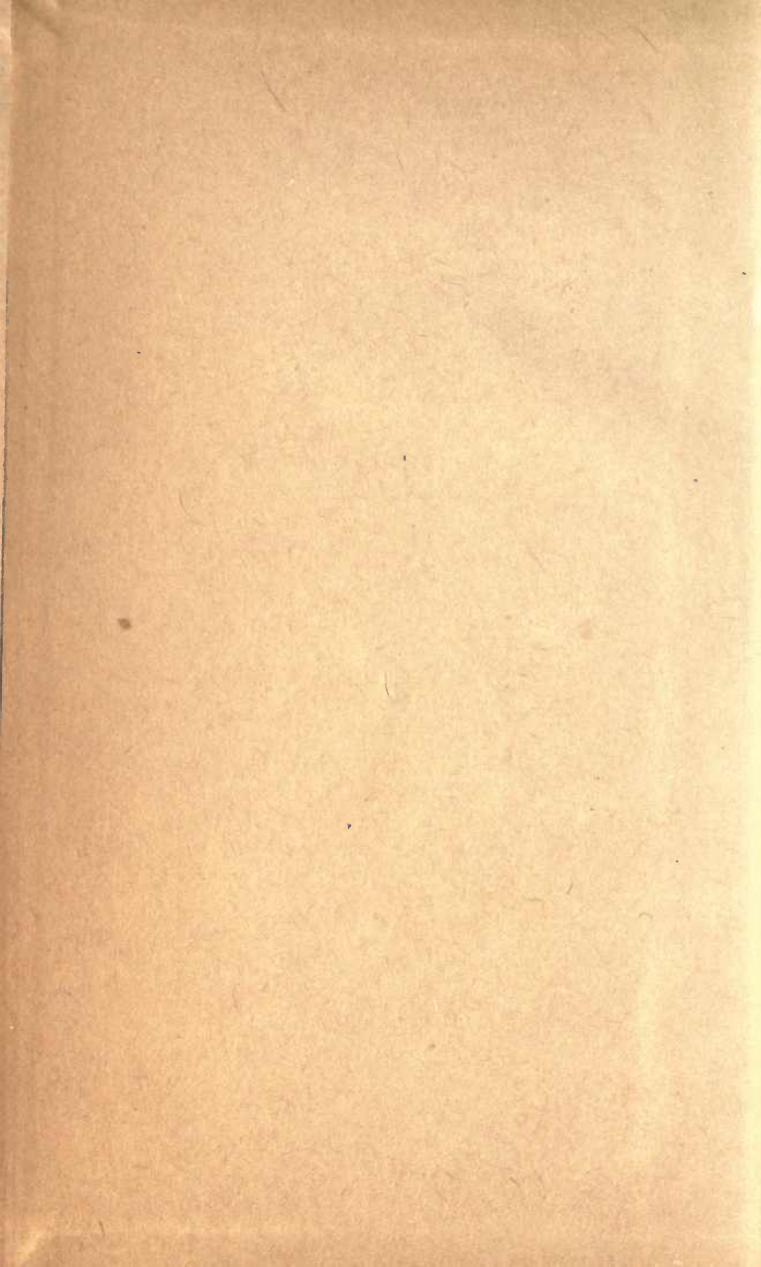
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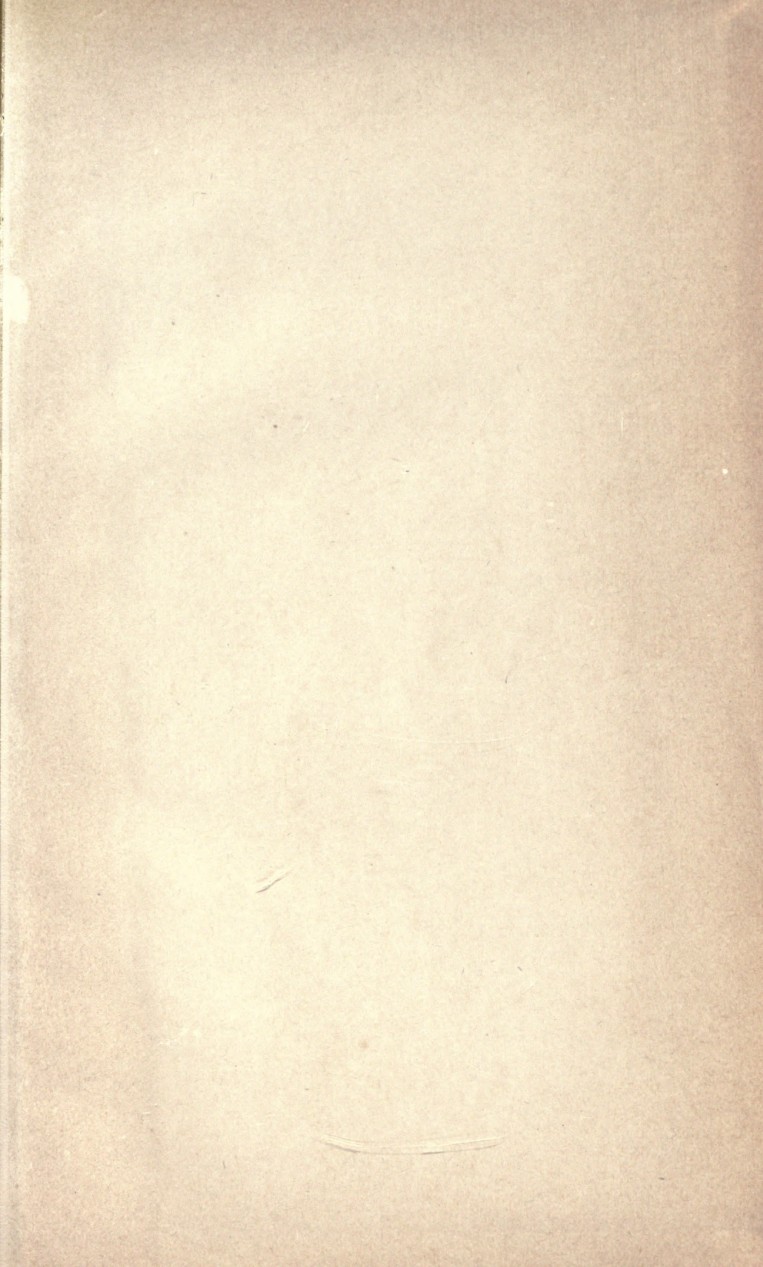
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THE OSCILLATION VALVE .





# THE OSCILLATION VALVE

THE ELEMENTARY PRINCIPLES OF ITS  
APPLICATION TO WIRELESS TELEGRAPHY

*Red*

BY

R. D. BANGAY

AUTHOR OF

"THE ELEMENTARY PRINCIPLES OF WIRELESS TELEGRAPHY"



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## PREFACE

THE invention and improvement of the Oscillation Valve has led to important and far-reaching developments in the art of Wireless Telegraphy. The new fields of possibility opened by this invention have as yet been only partially explored, but already the perfection of the wireless telephone and of the wireless compass are directly due to its agency.

The increasingly important part played by the valve in all modern wireless telegraph installations makes it essential that all those interested in telegraphic and telephonic communication should have at least an elementary knowledge of its action, its limitations, and the principles underlying its various uses. Of the many thousands of persons actively engaged on wireless work, few have the highly specialised technical knowledge necessary to appreciate the scientific articles published from time to time on the research work of experts. It is in the hope of assisting these, by treating the subject from a purely logical point of view, that this book has been written. In it the author has endeavoured to explain as simply as

possible some of the rather complicated phenomena which have been observed and usefully employed.

The variations in the circuits employed for adapting the valve to wireless telegraphy are too numerous to be dealt with individually in a work of this size, but the explanations are intended to cover the fundamental principles underlying the several distinct methods in common use.

The author takes this opportunity of acknowledging the valuable assistance he has received from Mr. G. M. Wright.

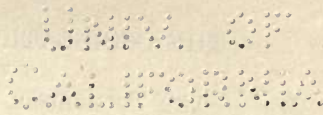
R. D. B.



# CONTENTS

	PAGE
GENERAL CONSIDERATIONS OF WIRELESS TELEGRAPH RECEIVERS . . . . .	1
The telephone receiver—Rectification of high-frequency oscillations—Conversion of high-frequency oscillations into low-frequency impulses—The ticker method of reception for continuous waves—The principles of “beat” reception for continuous waves—Tuning—Effect of damping on shape of resonance curve.	
THE VACUUM VALVE . . . . .	46
General considerations—The electron theory.	
THE FLEMING VALVE . . . . .	57
Characteristics of the Fleming Valve—The space charge—Application of the Fleming Valve to receiver circuits—Efficiency of rectification—The drop in potential along the filament—Application of Fleming Valve to low-frequency rectification.	
GENERAL CHARACTERISTICS OF THE THREE-ELECTRODE VALVE . . . . .	82
Effect of grid potential on valve current—Effect of filament brilliancy on valve curves—Effect of sheath potential on valve curves—Distribution of valve current between grid and sheath circuits—Effect of the mechanical proportions of the valve—Size of filament—Effect of grid mesh and distance of grid from filament on valve characteristics—“Magnification constant” of valves.	

THE APPLICATION OF THE THREE-ELECTRODE VALVE TO RECEIVERS . . . . .	110
The three-electrode valve as a rectifier—Efficiency of three-electrode valve as a rectifier—The grid condenser method of rectifying.	
THE VALVE AS A MAGNIFIER . . . . .	133
Magnifying properties of the valve—The valve as a note magnifier.	
HIGH-FREQUENCY MAGNIFICATION . . . . .	146
The tuned amplifier—The resistance amplifier—Semi-aperiodic amplifier.	
THE REACTION PRINCIPLE . . . . .	170
Use of reaction for reception of spark signals—Independent heterodyne method of detecting continuous wave signals—Self-heterodyne method of reception.	
THE APPLICATION OF THE THREE-ELECTRODE VALVE TO TRANSMITTERS . . . . .	186
Direct excitation of aerial—Power of transmitting valves—Generation of necessary sheath potential—Excessive heating of valves—Softening of valves—Indirect excitation of aerial.	
THE THEORY OF THE SOFT VALVE . . . . .	207
INDEX . . . . .	211



# THE OSCILLATION VALVE

## THE ELEMENTARY PRINCIPLES OF ITS APPLICATION TO WIRELESS TELEGRAPHY

### GENERAL CONSIDERATIONS OF WIRELESS TELEGRAPH RECEIVERS

1. ALTHOUGH the oscillation valve can be effectively used, as we shall show, in conjunction with wireless telegraph transmitters, a far more extensive use of its properties is made in connection with Receivers. We therefore propose to devote a few paragraphs to a brief survey of the problems met with when receiving wireless telegraph signals, with the hope that it will give the student a clearer appreciation of the descriptions that follow.

2. The essential purpose of a Wireless Telegraph Receiver is to convert groups or trains of electric waves which are radiated from the transmitting station into some form which is perceptible to the human senses, such as light or sound. In practically all Wireless Telegraph Stations sound-reading is adopted, and the Telephone Receiver is the ultimate detector by means of which the received signals are made audible.

## THE TELEPHONE RECEIVER

3. A section of a Telephone Receiver is illustrated in Fig. 1. A permanently magnetised steel magnet M is mounted in a containing case C. A pair of bobbins, B, surround the two poles of the magnet, and serve as a means of controlling to a limited extent the strength of the magnet. Mounted immediately in front of the magnet faces and separated only by a very small air space is a diaphragm D, consisting of a thin circular

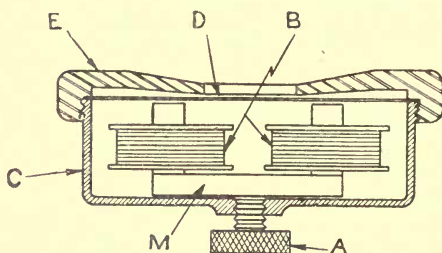


FIG. 1.

plate of soft iron. This diaphragm is supported on the face of the containing case and is held in position by an ebonite cover E, called the ear-piece, which also acts as a shield to prevent any pressure being put on the diaphragm by contact with the ear.

4. In some telephones, for the purpose of increasing their sensitiveness, the distance between the diaphragm and the magnet can be adjusted by means of a thumb-screw A, but for the sake of cheapness of manufacture this refinement is in most cases dispensed with.

5. Owing to the normal pull of the magnet, which, as already stated, is permanently magnetised, the diaphragm is buckled and bulges slightly towards the



magnet, until the pull exerted by the diaphragm due to the natural springiness of the iron of which it is made, and which tends to keep it flat, balances the pull of the magnet.

6. The initial magnetism of the telephone magnets has an important bearing on the sensitiveness of the telephone receiver for the following reason. The pull on the diaphragm is proportional to the square of the number of lines of force passing from the magnet to the diaphragm, so that the greater the initial flux the greater will be the additional pull for a given current passing through the windings.

7. For example, suppose the initial flux is 10 lines of force per square cm., and suppose the additional flux due to a certain current passing through the windings is 2, it follows that the additional pull on the diaphragm due to this current is  $12^2 - 10^2 = 44$ . Now suppose that the initial flux is 100 and that the additional flux due to the same current passing through the windings is as before, namely 2, then it follows that in this case the additional pull on the diaphragm due to this current is  $102^2 - 100^2 = 404$ , or nearly ten times as much as before.

At first sight it might appear that the sensitiveness of the telephones might be increased indefinitely by increasing the initial flux of the magnets. This, of course, is not so, as in any case the volume of sound which can possibly be produced is limited by the energy put into the telephones.

8. Any current passing through the telephone windings causes either an increase or a decrease in the pull on the diaphragm, according to whether the direction of the current is such as to increase or decrease the normal flux. And since the diaphragm is elastic and is

already in a state of tension, it follows that **the diaphragm will respond to any variation in the current flowing through the magnet coils** by moving either nearer to or farther away from the magnet, according to whether the variation in the current tends to increase or decrease the pull on the diaphragm.

9. Owing to its shape and the method of supporting it, the diaphragm is practically non-resonant, that is to say, it has, practically speaking, no natural time period of vibration, consequently it will respond more or less equally to different frequencies of variation in the current. Thus, if an alternating current be passed through the coils, having a frequency of anything up to, say, 10,000 cycles per second, the diaphragm will respond by moving alternately towards and away from the magnets in step with the current, and will thus produce sound-waves in the air corresponding in frequency to that of the alternating current.

10. It makes very little difference whether the current passing through the telephones be a true alternating current or a series of unidirectional impulses, except in the quality of the sound produced. The nearer the current variations follow a true sine law the purer will be the note of the sound produced. The pitch, however, is always the same as the frequency of the variations in the current.

#### RECTIFICATION OF HIGH-FREQUENCY OSCILLATIONS

Let us first see what result we should obtain by connecting the telephones directly in series with the oscillatory circuit of a Receiver.

11. In the first place, assuming for a moment that

the oscillatory currents could pass through the telephone windings and that the diaphragm of the telephone would vibrate at a corresponding frequency, the pitch of the sound produced would be far beyond the range of audibility (the highest audible note having a frequency of some 16,000 per second). Apart from this, however, the impedance of the telephone windings to a current of such high frequency would be so great as to prevent any appreciable current flowing through the coils, from which cause alone it is evidently quite impracticable to operate the telephones directly by the oscillatory currents. The combined effect of the inertia of the diaphragm and the impedance of the windings is such as to make the telephones comparatively insensitive to frequencies above 3000.

12. By using some form of rectifier in conjunction with a condenser it is possible to convert high-frequency oscillatory currents into a unidirectional and more or less uniform current which is capable of deflecting the diaphragm of the telephone.

13. **A rectifier is, essentially, a device which will only allow the passage of electricity through it in one direction.** Thus, if a rectifier be included in a circuit on which an alternating E.M.F. is impressed, it cuts off half of each complete alternation, with the result that the current flowing through the circuit consists of a number of unidirectional impulses. But although these impulses are unidirectional, they will have the same frequency as that of the impressed alternating current, and, therefore, a rectifier by itself is not necessarily sufficient to reduce an oscillatory current to a condition suitable for operating a telephone receiver.

14. If we connect an alternating current generator

directly across a condenser, the condenser becomes alternately charged and discharged, first in one direction and then in the other; but if we connect a rectifier in

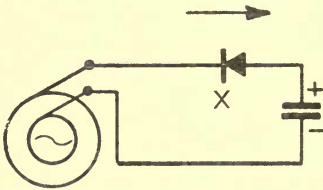


FIG. 2.

series with the circuit as shown by X in Fig. 2, then, owing to the fact that current can only pass through it in one direction, a current will flow from the generator into the condenser during

say, the first half-cycle, and this charge will remain in the condenser during the second half-cycle. Assuming that the voltage to which the condenser is charged is equal to the maximum applied E.M.F., *i.e.* the peak voltage, and that no leakage takes place from the

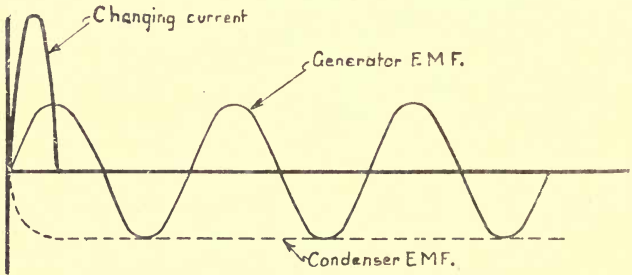


FIG. 3.

condenser, then it is evident that after the first quarter-cycle no more current can flow through the circuit.

15. We can illustrate these results by curves, as shown in Fig. 3, where the thin line curve represents the E.M.F. of the generator, the full line curve represents the current flowing from the generator through the



rectifier into the condenser, which only flows during the first quarter-cycle, and the thin dotted line curve represents the E.M.F. of the condenser, which rises to a value

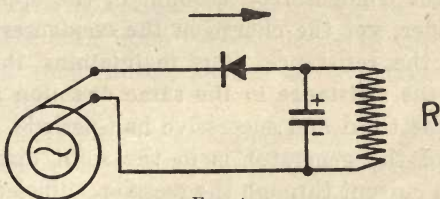


FIG. 4.

equal to the maximum generator E.M.F. during the first quarter-cycle, and remains thus charged indefinitely.

16. Now let us suppose that the condenser is provided with some path through which it can discharge slowly. Such a path could, for example, be made by connecting a high resistance across it, as shown in Fig. 4.

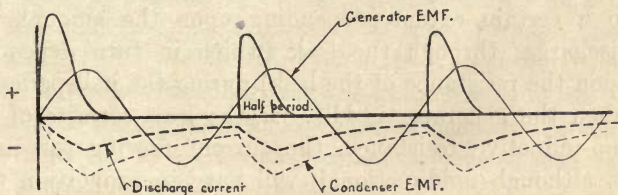


FIG. 5.

The result of applying an alternating E.M.F. through a rectifier to this circuit will be somewhat different from that noted in the previous case, and is shown graphically in Fig. 5.

17. During the first half-cycle a current as before will flow into the condenser and charge it up; at the same time a certain amount of current will also flow

direct from the generator through the resistance. During the second half-cycle, however, although no current can flow from the generator either through the resistance or into the condenser on account of the opposition of the rectifier, yet the charge in the condenser can flow through the resistance, **thus maintaining the current through the resistance in the same direction as before.** During the third and successive half-periods, when the E.M.F. of the generator is in the right direction for passing a current through the rectifier, sufficient current will flow from the generator into the condenser to make up for that expended by the condenser through the resistance during the idle half-period. Thus the condenser merely flattens out the peaks of the rectified current, and may be considered as a reservoir of electricity maintaining a more or less uniform current through the resistance.

18. The voltage of the condenser will, of course, vary to a certain extent, depending upon the amount it discharges through the leak (which in turn depends upon the resistance of the leak) during the half-periods when the generator is idle. If the leak consists of a non-inductive resistance, the current flowing through it, although unidirectional, will vary in proportion to the variation in the voltage of the condenser. If the leak be highly inductive, then the current flowing through it will scarcely be affected by small variations in the voltage of the condenser, but will gradually grow until it reaches a steady value proportional to the average value of the condenser voltage.

19. Although this effect is independent of the frequency of the alternator, and the arrangement can, therefore, be used either for rectifying the high-frequency

oscillations set up in the aerial circuit of a receiver by an incoming signal or for rectifying low-frequency alternations, yet it is important to note that **the degree of uniformity in the current** flowing through the inductive leak depends both upon the frequency of the applied E.M.F. and upon the inductance and resistance of the shunt circuit.

20. For example, let us suppose that the inductive shunt across the condenser has an impedance such that a normal charge in the condenser requires, say,  $\frac{1}{100}$ th second to discharge through that circuit, it is evident that if the frequency of the alternating current applied to the condenser through the crystal is 100 cycles per second, the current through the inductive leak **will rise to a maximum and fall to zero 100 times per second** so long as the applied alternating E.M.F. is maintained. On the other hand, assuming that the condenser and the shunt circuit remain as before, but that the frequency of the E.M.F. applied to the condenser through the crystal is 1000 per second, then it is evident that the current in the shunt circuit will gradually grow to a maximum during the first few alternations, after which **it will remain at a practically constant value so long as the alternating E.M.F. is maintained.**

21. The importance of this point will be more clearly seen when we remember that the purpose of the rectifier we are considering at the moment is to convert high-frequency oscillations into electrical impulses of a low enough periodicity to actuate the diaphragm of a telephone receiver.

22. The frequency of the oscillations set up in the receiver circuits by the incoming signal depends, of course, upon the wave-length being received, and may

be anything from 10,000,000  $\sim$  per second to 30,000  $\sim$  per second, representing wave-lengths between 30 metres and 10,000 metres. Such frequencies are known as **Radio Frequencies**. On the other hand, the frequency of the impulses actuating the diaphragm of a telephone depends upon the pitch of the note produced, and may be anything from 100 to 5000 cycles per second, and frequencies between these limits are known as **Note Frequencies**.

23. Thus it will be seen that if the reservoir condenser has a suitable capacity (depending upon the impedance of the circuit through which it has to discharge), variations of radio frequency in the E.M.F. applied to the condenser will cause no appreciable variation in the current flowing through the inductive leak, yet variations of note frequency will cause similar variations of the current in the inductive leak current.

24. A Rectifier is also frequently employed for the purpose of converting a low-frequency alternating current into a continuous unidirectional current of as nearly as possible constant value. The principle of applying the rectifier to such a purpose is exactly the same, but the capacity of the condenser must be perhaps thousands of times greater than what is required for "flattening out" radio-frequency impulses.

It only remains necessary to indicate broadly of what order the capacity of this condenser should be.

25. As already pointed out, the ultimate detector by which the received signals are rendered audible is the Telephone Receiver, and this, either directly or indirectly, forms the inductive circuit through which the rectified current flows. We say "directly or in-



directly" because the telephones are commonly used in conjunction with small transformers for the purpose of adapting a given type of telephones to a circuit whose resistance would be otherwise unsuitable.

26. It is evident that the capacity of the reservoir condenser when used for the purpose of reception should be such that it will discharge itself through the telephones, or through the transformer, as the case may be, in a length of time not greater than  $\frac{1}{4000}$ th part of a second, assuming that a frequency of 2000 is the highest note to which the telephones will be required to respond.

27. The inductance of a pair of telephones may be anything from .1 henry to 5 henries, according to whether they are of the low-resistance or high-resistance type. Assuming that their inductance is 1 henry, it can be shown that the value of the reservoir condenser should be not greater than .0006 microfarad. As a matter of fact, a best value of condenser will be found for different note frequencies and different strengths of signals, but so long as the capacity of the condenser is not too great a fixed condenser will give sufficiently good results over a wide range of note. If the capacity of the condenser be too large it will dull and muffle the note.

28. Nearly all standard telephones, more especially those of the high-resistance type, have a sufficient self-capacity in their windings to make any additional condenser superfluous, but however this may be, a clear understanding of the foregoing explanations of the principles underlying the rectification of high-frequency oscillations is important to enable the student to follow clearly the action of the apparatus described later.

29. When a rectifier is used for the purpose mentioned in paragraph 24 the capacity of the condenser necessary to flatten out the rectified impulses delivered to it depends upon the current which has to be dealt with, the frequency of the alternator, and the degree of uniformity required by the circuit which is being fed. No convenient rule can be given for defining the necessary capacity, but it may be of some use to give a practical example.

A condenser fed through a rectifier by an alternator having a frequency of 100 cycles requires a capacity of about  $\cdot 5$  microfarad to reduce the E.M.F. variation to 5 per cent, when the current dealt with by the condenser is of the order of  $\cdot 25$  ampere at 10,000 volts. A greater current would require a larger capacity, but a higher frequency would enable the capacity to be reduced to obtain a similar uniformity of E.M.F.

#### CONVERSION OF HIGH-FREQUENCY OSCILLATIONS INTO LOW-FREQUENCY IMPULSES

Before going further with the question of converting the electric waves into sound, let us examine the nature of the oscillatory currents produced in the high-frequency circuits of the receiver, as this has an important bearing on the choice of the various methods available.

30. In practice the transmitted signals may take one of three forms :

(1) They may consist of a continuous succession of undamped waves such as those radiated by a "continuous wave" transmitter, and illustrated by the diagram A, Fig. 6.

(2) They may consist of a series of groups or trains of

damped waves such as those radiated by a "spark" transmitter, and illustrated by the diagram B, Fig. 6.

(3) They may consist of a series of groups of undamped waves known as "interrupted continuous waves," or "tonic trains," and illustrated by the diagram C, Fig. 6.

31. The diagrams B and C do not show the true proportion between the length of time occupied by the train of waves and that occupied by the interval between successive wave groups. In the case of ordinary spark

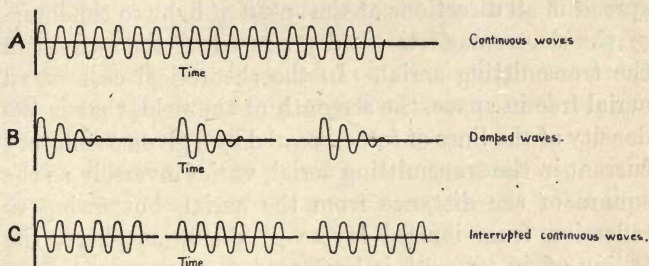


FIG. 6.

signals the damping is usually such that the waves die out after some fifty or more oscillations, which with ordinary wave-lengths and ordinary spark frequencies represents only about  $\frac{1}{50}$ th to  $\frac{1}{10}$ th of the total time interval between the commencement of successive groups.

In the case of interrupted C.W. or "tonic trains," the length of the group of waves depends entirely upon the arrangement used for chopping up the oscillations at the transmitting station, and is usually about  $\frac{3}{4}$ ths of the time interval.

32. An electric wave consists of a moving strain in the aether and can be resolved into two forces, namely,

the electromagnetic force and the electrostatic force. These forces act in certain directions along what are known as lines of force, the electromagnetic lines being at right angles to the electrostatic lines, and the direction of propagation being at right angles to both.

33. It simplifies problems when studying wireless phenomena to neglect the electrostatic component, and thus to assume that an electric wave consists only of a group of electromagnetic lines of force. These lines of force start out from the transmitting aerial, and rapidly spread in all directions at the speed of light to the limits of the electromagnetic field produced by the current in the transmitting aerial. In the theoretical case of an aerial free in space, the strength of the field, that is the density of the lines of force, created by a given oscillatory current in the transmitting aerial, varies inversely as the square of the distance from the aerial, but owing to reflection from ionised layers in the atmosphere, the falling off in strength is less rapid.

It is easy to see, then, that if we suspend another aerial wire in the aether within the electromagnetic field created by the oscillatory currents in the transmitting aerial, a certain number of the lines of force will cut this wire, and thus generate an E.M.F. in the second or receiving aerial wire. As the field builds up and collapses at a frequency equal to the frequency of the oscillations in the transmitting aerial, it is evident that the E.M.F. generated in the receiving aerial wire will also be oscillatory and have the same frequency as that of the transmitter. In the case of both the transmitter and receiver the aerial forms part of an oscillatory circuit, so that we may regard them as two very loosely coupled oscillatory circuits, one of which is being energised by the other.



34. The effect of coupling two oscillatory circuits is fully dealt with in other works,<sup>1</sup> and we must assume that the student is conversant with those phenomena. It will be sufficient for our purpose to point out that when the Receiving Aerial is tuned to the incoming signal, the oscillations in it are **gradually built up to a certain maximum amplitude**, until the rate at which the aerial loses energy (in operating the detector and radiating feeble waves) is equal to the rate at which it gains energy from the incoming signal. After this stage is reached the oscillations gradually die out. The only difference between this process and that obtained with comparatively closely coupled circuits is that no appreciable amount of energy is re-transferred back to the transmitting station.

35. The coupling between the transmitting aerial circuit and the receiving aerial circuit is so weak that only a very small proportion of the energy in the transmitting aerial is transferred to the receiving aerial. Although the receiving aerial again radiates a considerable amount of the energy it receives, for all practical purposes none of this energy is re-transferred back to the transmitting circuit and it therefore constitutes a loss.

36. It is sufficient for our purpose if we indicate graphically the nature of the oscillations induced in the receiving aerial by signals received from the different types of transmitters enumerated in paragraph 30 in so far as they concern the action of the apparatus we are about to describe. The chief points with which we are concerned are (1) **the amplitude** of the E.M.F., (2) **the persistence** of the oscillations. Although the oscillatory E.M.F. generated in the aerial will create a corresponding

<sup>1</sup> See *Elementary Principles of Wireless Telegraphy*, pars. 1183-1215.

current, there is no necessity to discriminate between the E.M.F. and the current, and we can thus considerably simplify our explanation by indicating only the E.M.F.

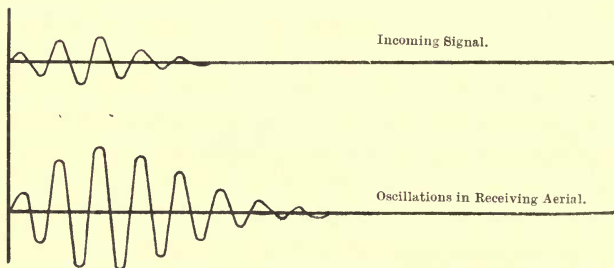


FIG. 7.

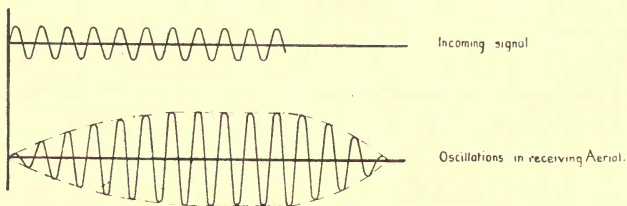


FIG. 8.

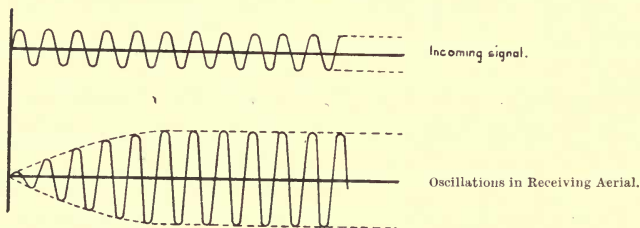


FIG. 9.

In Figs. 7, 8, and 9 we have illustrated the resulting oscillations in the receiving aerial circuit produced by the different forms of received signals.

37. A continuous current passing through the coils of a telephone receiver, as we have seen, will only have the effect of increasing or decreasing, according to its direction, the strength of the magnet, and will therefore cause the diaphragm to produce no sound beyond a single click due to its first displacement. It is evident, therefore, that even if the dots and dashes of the incoming signals could be distinguished by the time intervals between the clicks due to the commencement of the current and the clicks due to the cessation of the current, the energy received by the aerial from the incoming waves would be expended largely in passing a continuous current through the coils of the telephone, and wasted in heating up the coils instead of being utilised for the production of sound.

In order to produce the greatest volume of sound for a given amount of energy, we must, by some means or other, cause the current to vary during the otherwise silent parts of the dots and dashes so as to produce a series of clicks or a note, having a frequency of not less than about 100 and not more than 2000 vibrations per second.

38. In the case of signals received from "spark" or "interrupted C.W." transmitters, each dot or dash consists of a number of groups of oscillations, in which, although the oscillations themselves are of radio frequency, the groups of oscillations occur at a note frequency. It is evident, therefore, from the preceding explanation of the action of the rectifier, that **these signals will be delivered from the reservoir condenser to the telephones in the form of unidirectional impulses of note frequency, thereby producing a sound of the same frequency as the frequency of the spark or interruptions**

of the transmitter. In these circumstances there is obviously no need to employ any artificial means at the Receiving Station to break up or otherwise vary the current delivered by the rectifier to the telephones.

If, on the other hand, each incoming signal consists of a continuous train of undamped waves such as is produced by a continuous wave transmitter, it is necessary to use artificial means in the receiver to interrupt or vary rapidly the current flowing through the telephones.

### THE TICKER METHOD OF RECEPTION FOR CONTINUOUS WAVES

39. The obvious way of doing this is to employ some mechanical device known as a "Ticker" to interrupt the circuit. So far as the note produced in the telephones is concerned, the same effect will be gained if we interrupt either the aerial circuit or the telephone circuit. Neither of these methods of using the ticker is so sensitive as that illustrated in Fig. 10, which **in addition has the advantage of not requiring a rectifier.**

40. The principle on which it works is as follows. The energy received by the aerial is accumulated in the resonant circuit BC. When the ticker contact is interrupted no energy is dissipated, with the result that the amplitude of the E.M.F. of the condenser C builds up. This lasts for perhaps  $\frac{1}{1000}$ th part of a second. When the ticker contact is closed the energy stored up in the condenser C is transferred to the condenser T, which is connected across a pair of telephones. **This condenser must have a considerably greater capacity than the condenser C,** so that it has not time to discharge through the resonant circuit before the ticker contact is again interrupted.



When this happens the oscillations once more build up an E.M.F. in the condenser C, and at the same time the large condenser T discharges itself comparatively slowly through the telephone. This process repeats itself so long as the received train of waves continues, thus producing a series of clicks in the telephones.

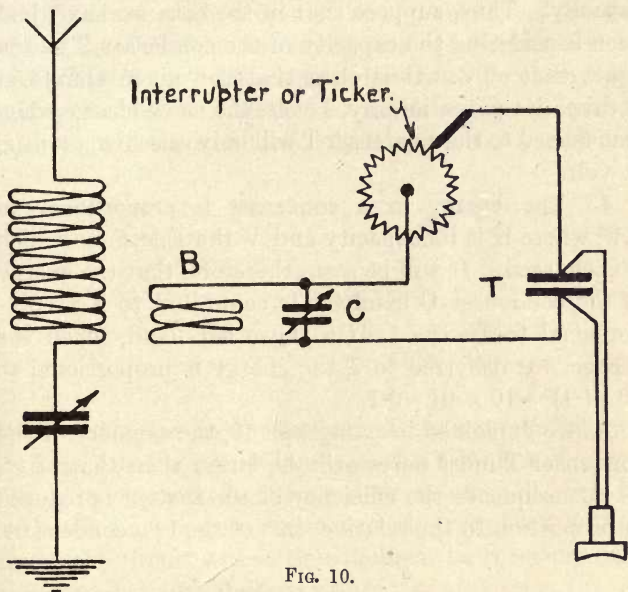


FIG. 10.

41. The rate of the interruptions of the ticker is necessarily quite independent of the frequency of the oscillations in the resonant circuit, and consequently the ticker sometimes makes contact when the E.M.F. across the condenser C is small, and sometimes when it is at its full value. The result is that the note produced in the telephones is somewhat uneven.

42. The efficiency of this "method of reception" is

necessarily low on account of the loss of energy which takes place when the charge in the small resonant condenser C is transferred to the comparatively large telephone condenser T. The reason for this loss is simple. **The voltage to which a condenser is charged by a given quantity of electricity is inversely proportionate to its capacity.** Thus, suppose that in the case we have just been considering the capacity of the condenser T is ten times that of C. It is clear that if a given charge in C raises its potential, say, 1 volt, the same charge when transferred to the condenser T will only raise its potential .1 volt.

43. **The energy in a condenser is proportional to  $KV^2$**  where K is its capacity and V the E.M.F. to which it is charged. It will be seen, therefore, that the energy in the condenser C before it is connected to T is proportional to  $1 \times 1^2 = 1$ . On the other hand, when the charge is transferred to T the energy is proportional to  $10 \times (.1)^2 = 10 \times .01 = 0.1$ .

As we explained in paragraph 40, the capacity of the condenser T must necessarily be larger than that of C; as a consequence the efficiency of the system is reduced in proportion to the relative sizes of the two condensers.

#### THE PRINCIPLES OF "BEAT" RECEPTION FOR CONTINUOUS WAVES

44. The methods just described of rendering undamped waves audible have been entirely superseded by another method, which, for reasons that will become clear when we deal in detail with the oscillation valve, is far more efficient. We refer to the method of **superimposing two radio-frequency oscillatory currents to obtain "beats"**

of note frequency. This is known most commonly as "Heterodyne" reception, "beat" reception, or the "interference" method of reception. For the present it will suffice to explain the theory on which it is based.

45. If two continuous-current generators are connected in series with a common circuit, then the resultant E.M.F. across that circuit at any moment will be the sum of the E.M.F.'s supplied by each generator. If the two E.M.F.'s are both acting in the same direction their values can both be indicated by the same sign, *i.e.* either + or -, and the resultant E.M.F. across the circuit will

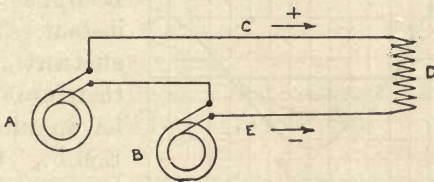


FIG. 11.

at that moment be the numerical addition of the two values. On the other hand, if the two E.M.F.'s are acting in opposite directions their values will each be indicated by opposite signs, and the resultant E.M.F. across the circuit will at that moment be the numerical difference between the two values.

46. For example, suppose the two generators A and B, Fig. 11, are both supplying an E.M.F. to the circuit CDE. If we call any E.M.F. which tends to cause a current to flow in the direction CDE positive, then an E.M.F. which tends to cause a current to flow through the circuit in the direction EDC will be negative. Thus if A is supplying +2 volts and B +3 volts, the resultant E.M.F. across D will be +5 volts, indicating that an

E.M.F. of 5 volts is acting in such a direction as would cause a current to flow through the circuit in the direction CDE. On the other hand, if A is supplying +2 volts and B -3 volts, the resultant E.M.F. across D will be -1 volt, indicating that an E.M.F. of 1 volt is acting in such a direction as would cause a current to flow in the direction EDC.

47. If the generators are supplying alternating currents, then the resultant E.M.F. across the circuit at

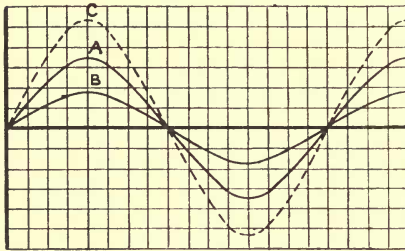


FIG. 12.

any instant will be the sum of the two E.M.F.'s at that instant. This resultant E.M.F., therefore, will also be an alternating E.M.F., but its maximum value will depend not

only on the maximum values of the two superimposed E.M.F.'s, but also upon their phase relation. The explanation of this can be better understood by referring to graphical illustrations.

48. In Figs. 12, 13, and 14 we have shown a single cycle of the two superimposed E.M.F.'s of the same frequency supplied by the generators A and B, by the two sine curves marked A and B respectively, and the resultant E.M.F. acting across the circuit (which can be plotted by adding the ordinates of the two E.M.F.'s at any instant) by the dotted curve C.

49. Fig. 12 represents the conditions when the two superimposed E.M.F.'s are exactly in phase. The



resultant E.M.F. is then greatest, because the two E.M.F.'s are always acting in the same direction across the circuit.

50. Fig. 13 represents the condition when the two superimposed E.M.F.'s are  $90^\circ$  out of phase. The resultant E.M.F. in this case is considerably less, because the two E.M.F.'s are never at their maximum values at the same instant.

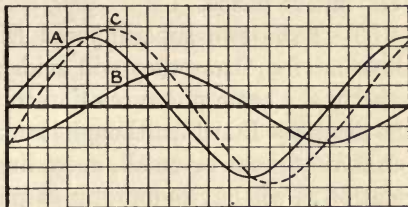


FIG. 13.

51. Fig. 14 represents the condition when the two superimposed E.M.F.'s are  $180^\circ$  out of phase. The

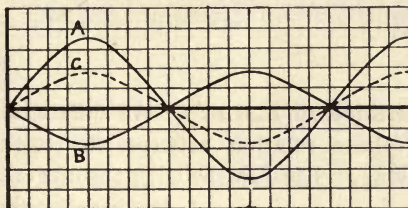


FIG. 14.

resultant E.M.F. in this case is least, because the two E.M.F.'s are at all times acting in opposite directions, and consequently at all moments the resultant E.M.F. is

the difference between the values of the two superimposed E.M.F.'s.

52. The important conclusion we may draw from this explanation is that if two alternating E.M.F.'s of the same frequency be superimposed on a common circuit, the resultant E.M.F. acting on that circuit will also be an alternating E.M.F. having the same frequency as the superimposed E.M.F.'s, and whose amplitude

will remain at a constant value according to the phase relation of the two superimposed E.M.F.'s, being greatest if the two E.M.F.'s are in phase, and least if the two are  $180^\circ$  out of phase.

53. If the two superimposed E.M.F.'s have exactly the same frequency they will evidently at all times bear exactly the same phase relation to one another, so that the resultant E.M.F., although its amplitude will be comparatively great or small, according to what this phase relation is, will have a uniform amplitude throughout the time that the two E.M.F.'s are acting. This condition covering a number of cycles is illustrated in Fig. 15.

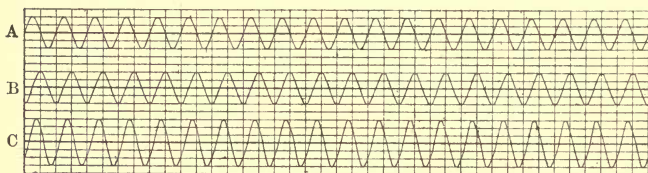


FIG. 15.

54. If the two superimposed E.M.F.'s have different frequencies, then the phase relation between the two will be constantly varying. The E.M.F. with the lower frequency will with each successive cycle lag more and more behind the one with the higher frequency, until the phase difference between the two reaches  $180^\circ$ . After this the phase difference will get less and less until they are once more in phase. Thus, to take an example, let us suppose that the frequency of A is 10 cycles per second and that of B 9 cycles per second; it follows that if both E.M.F.'s are in phase to start with they will be  $180^\circ$  out of phase at the middle of the fifth cycle, and exactly in phase again at the end of 9 cycles.

55. Since the amplitude of the resultant E.M.F. is greatest when they are in phase and least when they are  $180^\circ$  out of phase, it follows that under these conditions, *i.e.* when the two E.M.F.'s have different frequencies, the amplitude of the resultant E.M.F. will be constantly varying from a maximum to a minimum once in every second, as illustrated in Fig. 16. Thus, quite apart from the frequency of the resultant E.M.F., the variation in the amplitude of the resultant E.M.F. will have a definite frequency equal to the difference between the two frequencies.

It follows that if the frequencies of the two super-

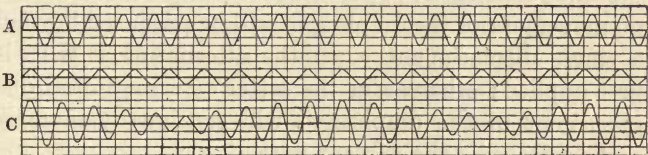


FIG. 16.

imposed E.M.F.'s are 100,000 and 100,001 per second respectively, the frequency of the variation in the amplitude of the resultant E.M.F. will still be 1 per second.

56. If the frequencies of the two superimposed E.M.F.'s be represented by  $n_1$  and  $n_2$  respectively, and the frequency of the variation in the amplitude of the resultant E.M.F. by  $N$ , then

$$N = n_1 - n_2.$$

57. Let us now see the effect of applying this principle to a similar circuit to that shown in Fig. 4, namely, to one consisting of a reservoir condenser fed through a rectifier and shunted by a telephone. It is evident that

if the circuit be fed by two superimposed alternating currents of the same radio frequency, the current through the telephones (*vide* paragraphs 19 and 20) will be unidirectional and will have a uniform value. But if the circuit be fed by two alternators having slightly different radio frequencies, the variation in the amplitude of the resultant E.M.F. will be slow enough to effect the value of the current flowing through the inductive leak, the frequency of the variations being equal to the difference between the frequencies of the two superimposed E.M.F.'s.

58. It follows that in the former case, when the two superimposed E.M.F.'s have the same radio frequency, no movement of the diaphragm will be produced beyond a single displacement when the alternating E.M.F. is first applied; whereas in the latter case the initial displacement of the diaphragm will continually increase and decrease as the current varies.

59. This is the principle of beat reception, on which all modern continuous wave receivers are based. In the explanation we have given we have taken the case of two alternating current generators supplying the current at the same or slightly different frequencies to a common circuit. In the case of a Wireless Telegraph installation which is receiving continuous wave signals from some distant source, a high-frequency generator is installed and controlled close to the receiver. This generator, which we shall refer to as the "local generator," is connected to the receiver circuits in such a way as to maintain continuous oscillations having a frequency which can be exactly controlled. Consequently, when no signals are being received, the reservoir condenser of the receiver is kept uniformly charged, and therefore



a uniform continuous current flows through the telephones so long as the local oscillations are maintained. This current, being uniform, produces no sound in the telephones beyond the initial click when the generator is first connected.

60. The alternating E.M.F. which is superimposed on the same receiver circuit is that produced by the incoming signal. It will be clearly seen, then, that if the frequency of the local receiver generator is so adjusted as to be slightly different from that of the E.M.F. generated by the incoming signal, the result will be that the E.M.F. to which the reservoir condenser is charged through the rectifier will be made to vary from a certain maximum (*i.e.* the local E.M.F. plus the received E.M.F.) to a certain minimum (*i.e.* the local E.M.F. minus the received E.M.F.), the frequency of this variation depending upon the difference between the frequency of the local generator and that of the incoming signal. Consequently, the current flowing through the telephones will also vary at a similar frequency, causing the diaphragm of the telephone to vibrate and produce a musical note. By adjusting the frequency of the local generator the note produced by the combined effect of the two E.M.F.'s can be varied to any desired pitch.

61. This note would, of course, only be produced so long as both the local generator and the incoming waves are maintained, and therefore, assuming that the local generator is kept continuously running and that the incoming waves are sent out from the transmitting station in short and long trains, representing the dots and dashes of the Morse code, these signals will be reproduced in the telephones of



the receiver as notes of definite pitch but of short and long duration.

62. Similar conditions to these can be reproduced in the case of the experiments described in previous paragraphs, if one of the alternators can be cut out of circuit by a switch which can be opened or closed at will. Thus, suppose the generators A and B in Fig. 17 are connected in series with the circuit CD, consisting of a rectifier D and a condenser C, and suppose that the generator B can be cut out of circuit by a switch S.

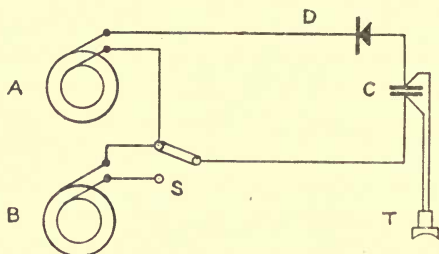


FIG. 17.

Let us also suppose that the frequency of the generator B which represents the incoming signal is definite, and that the frequency of the generator A can be controlled.

63. It is evident that while the switch S is in the position shown, owing to the action of the rectifier D the condenser C will be kept uniformly charged to a certain value, and that if a telephone T be connected across this condenser, a uniform current will flow through it, producing no sound beyond the initial click occurring when it is first connected.

64. These conditions are illustrated by curves in Fig. 18, in which A represents the E.M.F. generated by the alternator A and applied to the circuit CD. The thick

line in the curve D represents the current flowing through the rectifier into the condenser, which, owing to the action of the rectifier, can only flow during every other half-cycle, and is just sufficient to make up for the current flowing out of the condenser through the telephones. The thin line curve represents the E.M.F. to which the condenser is charged. The curve E represents the current flowing from the condenser through the telephone T. It will be noted that this current rises slightly to a certain maximum value and then remains constant. For the sake of simplicity we have drawn it as though

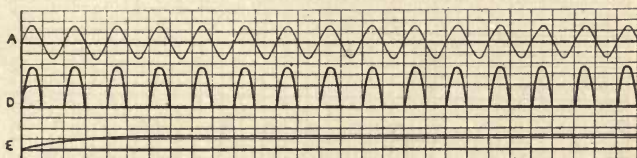


FIG. 18.

the current reached this maximum value by about the end of the second cycle. In actual practice, however, owing to the very high inductance of the telephones compared with the frequency of the alternating E.M.F., the current through the telephones would actually take several hundred cycles to reach its maximum value.

65. Now let us suppose that the switch S is opened, thus connecting the alternator B to the same circuit CD, so that its E.M.F. is superimposed upon the E.M.F. generated by A. The results in the circuit are illustrated by the curves in Figs. 19 and 20, those in Fig. 19 showing what would occur if A had exactly the same frequency as B, and those in Fig. 20 showing what would occur if the frequency of A is slightly different from that of B.

66. In both Figs. 19 and 20 the curve A represents the E.M.F. generated by the generator A and the curve B that generated by B. As indicated, we have assumed that the two E.M.F.'s are  $90^\circ$  out of phase and that the switch S is closed at the moment  $M_2$ . The resultant E.M.F. across the circuit DC is indicated by the curve C. The current flowing into the condenser through the rectifier and the voltage to which this condenser is charged is indicated by the curve D, the thick line

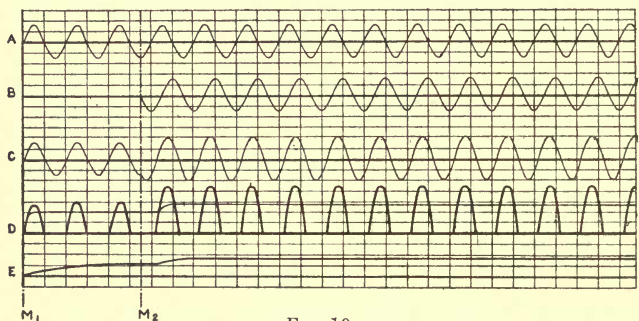


FIG. 19.

curve indicating the current and the thin line curve the E.M.F. The current flowing from the condenser through the telephones is indicated by the curve E.

67. From an examination of the curves illustrated in Fig. 19 the following points will be noted. Up to the moment  $M_2$ , when only one generator is acting on the circuit, the resultant applied E.M.F. is the same as the E.M.F. of that generator. Thus the condenser is quickly charged to a certain value which remains constant, and the current flowing through the telephone, after rising to a steady value, also remains constant, as indicated by the curve E. After the moment  $M_2$ ,

when the second generator is caused to act on the circuit, the resultant applied E.M.F., as indicated by the curve C, increases in amplitude, resulting in an increase in the steady voltage of the condenser, as indicated by the curve D, and a corresponding increase in the current flowing through the telephones, which, after reaching a new maximum value, again remains constant.

Since the diaphragm of the telephone responds only to a variation in the current flowing through the windings,

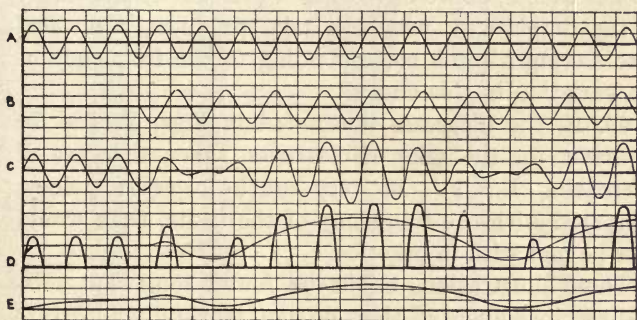


FIG. 20.

only single clicks will be heard, one at the moment  $M_1$ , when the first generator is connected to the circuit, and another at the moment  $M_2$ , when the second generator is switched on.

68. Examining the curves in Fig. 20, which illustrates the results obtained when the two alternators have slightly different frequencies, it will be noted that up to the moment  $M_2$ , as before, the current flowing through the telephones, as indicated by E, remains at a steady value. After the moment  $M_2$ , however, the resultant voltage, as indicated by the curve C, starts alternately to

increase and decrease in amplitude as the two superimposed currents come in and out of phase. The result is that the E.M.F. of the condenser as indicated by D, although never reversing in value, also increases and decreases in step with the variation of the amplitude of the applied E.M.F., thus causing a corresponding variation in the current flowing through the telephones as indicated by the curve E, after the moment  $M_2$ . This variation in the current flowing through the telephones causes, as we have seen, a periodic displacement of the diaphragm, which in turn produces a musical note having a pitch corresponding to the frequency of the variation in this current.

69. In the diagrams illustrated in Figs. 19 and 20 we have, for the sake of clearness, taken the case of alternating E.M.F.'s of very much lower frequency, compared with the frequency of the beats, than would ever be met with in practice.

These illustrations might be found somewhat misleading, inasmuch as they do not truthfully illustrate the comparative lag in the telephone current due to the high inductance of the circuit, which, as explained in paragraph 18, is largely responsible for the uniformity of this current; we have, therefore, endeavoured to illustrate in Fig. 21 the curves in their true proportions for a practical example in which the radio frequency of the two superimposed E.M.F.'s is 50,000 and 49,500 cycles per second respectively, corresponding to a wavelength of about 6000 metres, and in which the note frequency of the beats produced is 500 per second.





## TUNING

70. "Tuning" is a somewhat ambiguous term, which is frequently used in a wrong sense. Strictly speaking, tuning is the act of adjusting the frequency of an oscillatory circuit into resonance with an applied periodic force, or *vice versa*.

71. "Sharpness of Tuning" is an expression used to indicate the comparative sensitiveness of an oscillatory circuit to a small change from resonance in the frequency of the periodic force applied to it. This sensitiveness is measured by the final value of the current flowing in the circuit. By "final value" we mean that value which the current will attain after the periodic force has been acting on the oscillatory circuit for an infinite length of time. For this purpose we may take either the root-mean-square value of the current during one cycle or the amplitude of the cycle.

72. For example, suppose we have a periodic force of given strength and of constant frequency acting on an oscillatory circuit whose natural frequency can be varied, within reasonable limits, above and below the frequency of the applied force.

73. If there were no loss of energy in the oscillatory circuit, that is, if the oscillatory circuit were undamped, then the current flowing in it would increase with each successive swing. In other words, the amplitude of the current would build up, so long as the applied force is acting in synchronism with the oscillations in the circuit.

74. In the case of an undamped circuit so adjusted as to be exactly in resonance with an applied periodic force, the latter will always be acting in synchronism

with the current flowing in the oscillatory circuit. Consequently the amplitude, and therefore also the average value of the current in the circuit, would continue to increase indefinitely. In such circumstances the final amplitude of the current would be infinitely great.

75. This result can be explained in a somewhat simpler way if we look upon the force as a source of energy and upon the oscillatory circuit as a receiver and storer of energy. It is evident that so long as the force is acting in such a way as to assist the flow of current in the oscillatory circuit, the latter gains energy and the amplitude of the current increases at an average rate depending upon the average value of the assisting force ; but when the force acts in such a way as to oppose the flow of current in the oscillatory circuit, the latter loses energy and the amplitude decreases at an average rate depending upon the average value of the opposing force.

76. When an oscillatory circuit is in tune with the applied periodic force, the latter will at all times be acting in such a way as to assist the flow of current in the former, and therefore the oscillatory circuit will indefinitely continue to gain energy and the amplitude of the current will increase at a certain definite rate depending upon the average value of the applied periodic force.

It follows that if there is no loss of energy in the oscillatory circuit the energy stored in it, as represented by the amplitude of the current flowing, will continue to grow until it reaches an infinite value after an infinite length of time.

77. Thus the final result of an undamped periodic force acting for an infinite length of time on an undamped circuit adjusted to resonance is an infinitely large current ;

or rather an oscillatory current having an infinitely large amplitude flowing in that circuit.

78. If the frequency of the oscillatory circuit is slightly different from that of the applied periodic force, that is to say, if the circuit is slightly mistuned, then it is clear that the applied force will sometimes be assisting and sometimes opposing the flow of current in the oscillatory circuit. Thus the oscillatory circuit will be alternately gaining and losing energy.

79. The effect of this will be to create a series of beats in the amplitude of the current flowing in the oscillatory circuit similar to those observed in the previous chapter, when two alternating E.M.F.'s of

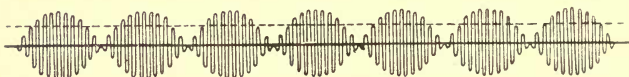


FIG. 22.

different frequency were superimposed on a common circuit. The frequency of these beats will depend, as before, upon the difference between the frequency of the oscillatory circuit and that of the applied periodic force.

80. It is evident, therefore, that when the oscillatory circuit is out of tune with the applied periodic force, **the amplitude of the current flowing in the circuit will never become infinitely large**, but will rise to a certain limit and fall to zero periodically, as illustrated in Fig. 22. The maximum value which it can attain will obviously depend upon two factors, (1) the strength of the applied periodic force, and (2) the frequency of the beats.

81. The greater the strength of the applied force, the greater will be the rate of increase in the amplitude of the current flowing during the time that the direction of

that force is assisting the flow of current in the oscillatory circuit. But since its maximum amplitude depends also upon the length of time during which it is increasing, and since this length of time is limited by the time period of the beats, it follows that for a given applied periodic force the maximum amplitude which the current will attain is inversely proportional to the frequency of the beats.

82. The frequency of the beats will be equal to the difference between the frequency of the applied periodic force and that of the oscillatory circuit (*vide* paragraph 56). Therefore the maximum value to which the current in the oscillatory circuit can grow is inversely proportional to the difference between the two frequencies, *i.e.* to the amount they are out of tune.

83. We may say, therefore, that the cumulative effect of an undamped periodic force acting for an indefinite length of time on an undamped oscillatory circuit which is not adjusted to resonance is to cause a current to flow in that circuit whose average amplitude is inversely proportional to the difference between the frequency of the applied force and that of the oscillatory circuit.

84. These results can be conveniently illustrated by a curve diagram known as the **resonance curve**, showing the relation between the tuning of the oscillatory circuit and the current (or the average amplitude of the current, as indicated by the dotted line in Fig. 22) which will flow in it as the result of a constant applied periodic force. Such a curve is illustrated in Fig. 23, in which the ordinates indicate the average amplitude of the current, *i.e.* the final effect of the applied periodic force, and the abscissae indicate the differences between the



frequency of that force and the frequency of the oscillatory circuit. The zero point on the abscissae obviously indicates the condition of resonance.

### EFFECT OF DAMPING ON SHAPE OF RESONANCE CURVE

85. In the foregoing paragraphs we have supposed

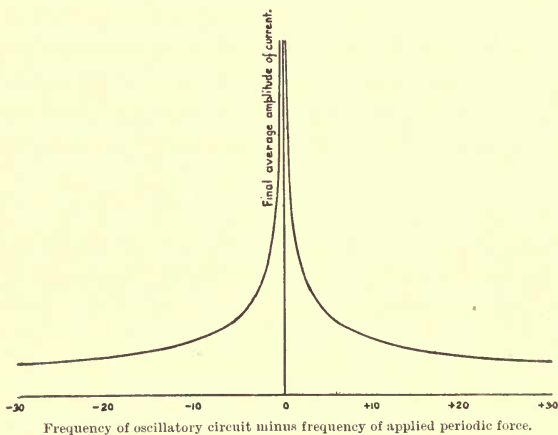


FIG. 23.

that the oscillatory circuit was undamped, and the resonance curve illustrated in Fig. 23 is plotted on this assumption. Let us now see what is the effect on the shape of this curve if, as is always the case in practice, a certain loss of energy takes place in the circuit; in other words, let us suppose that the circuit is to a certain extent damped.

86. Whether the loss of energy be due to radiation or resistance, it can be taken, for all practical purposes, as

being proportional to the square of the current flowing in the circuit.

87. Taking the case when the force and the circuit are in resonance, the rate at which the amplitude of the current increases is uniform. But since the energy it loses is proportional to the square of the current flowing, it is clear that the rate at which it loses energy rapidly increases with each successive cycle. Therefore, although at the commencement this loss may be quite small compared with the gain of energy, a time will be reached when the current has grown to such a value that the circuit loses energy in overcoming resistance and radiation at the same rate at which it gains energy from the applied periodic force. **After this point is reached the amplitude of the oscillatory current will evidently remain constant.**

88. The greater the damping of the oscillatory circuit, the sooner will the current reach its maximum amplitude, and therefore for a given applied periodic force the smaller will be the actual amplitude of this maximum current.

89. We may say, therefore, that the final effect of an undamped periodic force of given strength acting for an infinite length of time on a damped oscillatory circuit **adjusted to resonance** is to cause only a limited current, or rather an oscillatory current of limited amplitude, to flow in that circuit. The extent to which it is limited depends, as we have seen, upon the amount of damping in the circuit.

90. If the frequency of the damped oscillatory circuit is different from that of the applied periodic force, that is to say, if the circuit be mistuned, then, as in the case of the undamped circuit, the maximum amplitude

which the current can reach will be limited by the frequency of the beats produced. But besides this, owing to the additional loss of energy which takes place during each beat due to the damping, it is evident that the maximum, and therefore also the average value of the current for a given frequency of beats, will be always less in the case of the damped circuit than in that of the undamped circuit.

91. The effect of damping on the shape of the resonance curve is obviously to flatten out the peak, as shown in Fig. 24, where, for the sake of easy comparison, we have dotted in the theoretical resonance curve of an undamped circuit. The greater the damping the flatter the resonance curve becomes; thus the lower curve in Fig. 24 represents the results obtained with a more highly damped circuit.

92. At first sight it would appear that the beats in the amplitude of the current, generated in the oscillatory circuit by a mistuned and undamped applied periodic force, would persist so long as the force is maintained. In the theoretical case of an undamped circuit this would actually occur. But in the practical case of the circuit in which there is a certain amount of damping, no matter how insignificant the loss may be, the beats in the amplitude of the current only occur at the commencement, and gradually die out, with the result that **the amplitude of the current gradually reaches a final steady value equal to the average amplitude during the beats.**

93. This point will be more clearly understood by referring to the illustration in Fig. 25. In Fig. 22 we illustrated the oscillatory current which would be generated **in an undamped circuit** mistuned to the applied periodic force. In this case the beats would

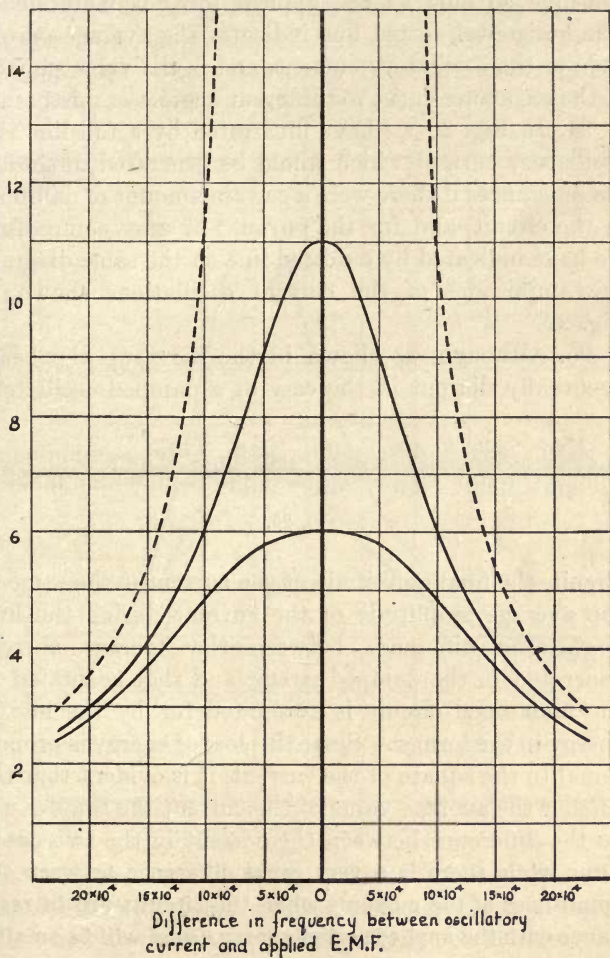


FIG. 24.

continue so long as the applied force is maintained. The horizontal dotted line indicates the average amplitude of the oscillatory current, and is the value plotted in the resonance curve for different degrees of mistuning.

94. In Fig. 25 we have illustrated by a full line the oscillatory current which would be generated in similar circumstances if there were a certain amount of damping in the circuit, and for the purpose of easy comparison we have indicated by a dotted line on the same diagram the amplitudes of the current oscillations shown in Fig. 22.

95. Although, as shown in the diagram, the beats eventually die out in the case of a damped oscillatory

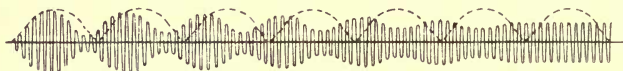


FIG. 25.

circuit, the final amplitude of the current is the same as the average amplitude of the current during the first beat. The difference between the average current generated in the damped circuit and that generated in the undamped circuit is accounted for by the loss of energy in the former. Since this loss of energy is proportional to the square of the current, it is evident that the smaller the average value of the current the smaller will be the difference between the current in the two cases. **Thus while there is a very great difference between the amplitudes of the currents when the circuits are in resonance with the applied periodic force, there will be smaller and smaller difference between the amplitudes of these currents as the two are adjusted further and further out of resonance.**



96. In the foregoing explanation, for the sake of simplicity, we have assumed throughout that the applied periodic force was undamped. If this force is damped

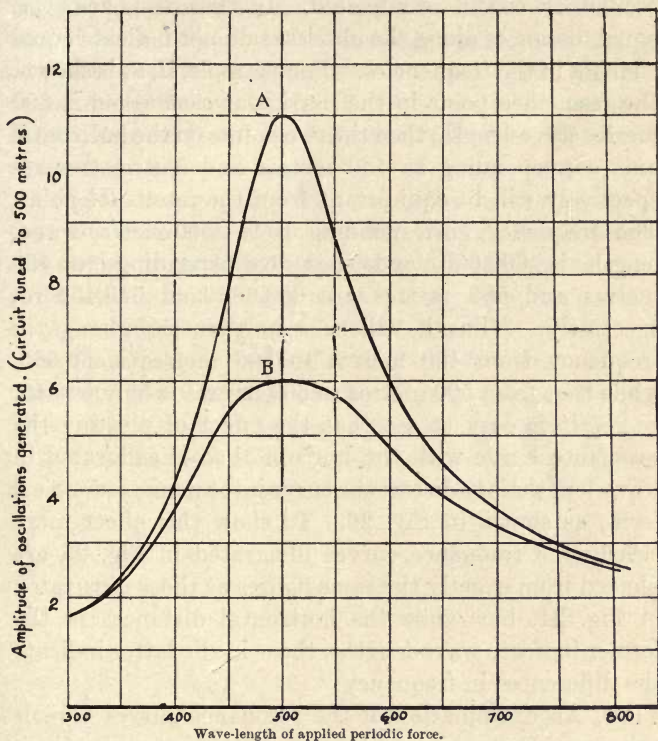


FIG. 26.

the effect on the shape of the resonance curve is exactly the same as the effect of damping in the circuit. The resonance curve, therefore, in practice always shows the combined effect of the two dampings, *i.e.* the sum of the damping of the applied force and that of the circuit.

97. In practice it is more convenient to plot the resonance curves as shown in Fig. 26, in which the abscissae indicate the actual wave-lengths to which the oscillatory circuit is adjusted. In this case, however, equal distances along the abscissae do not indicate equal changes in the frequencies. For example, if, as is shown, the resonance point in the particular case taken is 500 metres wave-length, then the two points on the horizontal axis corresponding to 450 metres and 550 metres respectively will be equidistant from the resonance point. The frequency corresponding to a 500-metre wave-length is 600,000, and those corresponding to 450 metres and 550 metres are 666,666 and 545,454 respectively. Thus it will be seen that the change in frequency from 450 metres to 500 metres is 66,666, while that from 500 metres to 600 metres is only 54,546.

98. It is easy to see that the effect of plotting the resonance curve with the horizontal scale calibrated in wave-lengths is to distort the curve into an unsymmetrical form, as shown in Fig. 26. To show this effect more clearly the resonance curves illustrated in Fig. 26 are plotted from exactly the same figures as those illustrated in Fig. 24, but while the horizontal distances in the former indicate wave-lengths, those in the latter indicate the differences in frequency.

99. An examination of the resonance curves reveals two important points. In the first place, they show that **an oscillatory circuit is capable of absorbing or receiving from a given applied periodic force a very much greater amount of energy when it is tuned to resonance than when it is out of tune.** For example, taking the energy as being proportional to the square of the current, we find by referring to the resonance curves illustrated

in Fig. 26 that in the particular case illustrated by the curve A the cumulative effect when the circuit is tuned to resonance, *i.e.* to a 500-metre wave-length, is three times as great as when the circuit is tuned to a 400-metre wave-length. Similarly in the case of a more highly damped circuit, as illustrated by the curve B, the cumulative effect when the circuit is tuned to resonance is less than twice as great as when the circuit is tuned to a 400-metre wave-length.

100. In the second place, the resonance curves show that the reduction of energy due to slightly mistuning the circuit is greater in the case of a slightly damped circuit than in the case of a highly damped circuit. For example, changing the wave-length to which the circuit is adjusted from 500 metres to 480 metres reduces the current in the case of the slightly damped circuit from 11 to 10, *i.e.* by 10 per cent, while a similar change in the wave-length of the highly damped circuit reduces the current from 6 to 5.9, *i.e.* by only 2 per cent.

## THE VACUUM VALVE

### GENERAL CONSIDERATIONS

101. IN the preceding paragraphs we have discussed in a general way the various problems which must be overcome in the reception of Wireless Telegraph Signals, and the manner in which the incoming signals can be converted into sound-waves audible to the human ear.

We have seen how the aether waves build up high-frequency electrical oscillations in the high-frequency circuits of the receiver, and how by the use of a suitable rectifier the oscillations can be converted into low-frequency impulses capable of actuating the diaphragm of a telephone receiver.

102. By far the most important part in the reception of wireless telegraph signals at the present time is played by the vacuum valve, which, in addition to its rectifying properties, has been so developed as to enable the most feeble variations in current to be greatly magnified.

We may take it for granted for the moment that, in the vacuum valve, we have an instrument which will rectify an alternating E.M.F., and which will also reproduce in a greatly magnified form the most feeble variations in any E.M.F. applied to it, no matter what its frequency. Assuming this, let us consider to what

uses these properties can be put in increasing the efficiency of the apparatus at our disposal.

103. Firstly, we may use the valve as a rectifier of high-frequency oscillations, to enable the currents generated in the aerial by the incoming signals to operate the Telephone Receivers. When used in this capacity the valve is known as a "**rectifier.**"

104. Secondly, we may use the valve to magnify the variations in the E.M.F. thus produced across the telephones, and in this way create a bigger sound effect in the telephones. When used in this manner the valve is known as a "**note magnifier,**" or "**low-frequency magnifier,**" because the variations in the current with which it is then dealing, whether they be in the nature of alternations or unidirectional impulses, are of note frequency.

105. Thirdly, we may use the valve to magnify the high-frequency E.M.F. generated in the aerial by the incoming signal, thus increasing the amplitude of the high-frequency oscillations set up in the receiver. When used in this capacity the valve is known as a "**high-frequency amplifier,**" because the variations in the current with which it is then dealing are of radio frequency.

106. A fourth, though less obvious, use to which the valve can be put is the generation of high-frequency undamped oscillations in an oscillatory circuit. When used in this capacity it is known as an "**oscillator**" or "**high-frequency generator.**"

Before we can attempt to explain these various functions, and before the student can appreciate how the necessary conditions can be brought about, it is essential that he should have a thorough and compre-



hensive knowledge of the characteristics of the valve and the extent to which these characteristics can be controlled.

### THE ELECTRON THEORY

107. Until comparatively recent years no satisfactory explanation was offered of many of the electrical phenomena known to science. As the application of electricity developed, an immense amount of data was accumulated which enabled scientists to deduce some of the laws which govern the flow of electricity. For example, the law governing the relation between pressure, current, and resistance was deduced by Ohm, and is known universally as Ohm's Law.

108. Discoveries were also made regarding the generation of electric pressure, first by chemical action between liquids and different metals, which lead to the evolution of batteries; and later by causing a conductor to cut a magnetic field, which lead to the evolution of the dynamo. Although at the time no satisfactory explanation of these phenomena was offered, yet it was of great practical value to determine from the results obtained experimentally the laws which govern these phenomena. It also became necessary to fix certain arbitrary standard units by which electrical force and energy could be defined, and these standards have been adopted universally by common consent.

109. Amongst other things it became necessary to define the direction in which electricity flowed through a conductor, and it was agreed to call the terminal fixed to the copper plate of a primary cell the positive terminal, and that fixed to the zinc plate the negative terminal, and to assume that **the electric current flowed, in an**

external circuit, from the positive terminal to the negative terminal. It must be understood, however, that this assumption was entirely arbitrary, and was made simply for convenience in defining certain phenomena.

110. Up to that time the atom was regarded as the smallest unit into which matter could be divided, and chemical and physical phenomena were explained as far as possible on this theory.

111. In recent years, however, scientists have discovered that the atom is itself subdivided into many thousands of particles, which they have termed "electrons," and that these electrons carry with them a charge of electricity. The new theory built up on this and other discoveries is known as the "**Electron Theory of Matter.**"

112. It would not upset any of the previously accepted principles of electricity and magnetism if it were assumed that the current in an external electrical circuit flows from the negative terminal to the positive terminal. This assumption fits in very well with the electron theory, because it is found that **the flow of electrons in an electric circuit is opposite to the direction (as universally defined) of the resulting current.**

113. Since positive and negative are purely relative terms, it becomes a simple matter to conform the new Electron Theory to the old theory of the direction of the flow of electricity by assuming that **an electron carries a negative charge of electricity**, or by considering it as a particle of negative electricity.

114. It has been shown scientifically that  $10^{19}$  electrons are equal to one coulomb of electricity, therefore the electrical magnitude of an electron can be defined as  $10^{-19}$  coulomb. It follows that if  $10^{19}$  elec-

trons pass from one point in an electric circuit to another in one second, they represent a current of one ampere flowing in the opposite direction between those two points.

115. It is by means of electrons that electricity is carried through conductors or through a vacuum. There is, however, a distinct difference in the two cases, which it may be as well to explain in order to prevent misunderstanding, and to assist the student to keep in view a more complete mental picture of what takes place in the different phenomena we are about to describe. In the present state of our knowledge of the subject the author lays no special claim to the detailed scientific accuracy of the following explanations. He presents them in the hope of fulfilling some useful purpose by giving the reader a simple working theory, to assist him in co-ordinating the varied phenomena which will come under his observation.

116. A vacuum can be regarded as pure unadulterated aether containing no particles of matter and offering no frictional resistance to the passage of particles of matter through it.

Matter, on the other hand, can be regarded as a collection of particles known as "atoms," which, although they are packed very closely together, do not actually touch each other. Each atom, as already explained, consists of thousands of electrons, the exact number and arrangement of which, although varying in different substances, is definite for any particular substance. Thus the number and arrangement of the electrons forming atoms of Hydrogen are always identical but are quite different from the number and arrangement of the electrons forming an atom of Oxygen.

117. The space between the atoms in any substance is filled partly by aether and partly by a number of loose electrons, and it is these loose electrons which provide the means of passing electricity through the substance.

118. A simple mechanical analogy will serve to illustrate the difference between the conduction of electricity through a vacuum and through a conductor.

Let us suppose that we wish to pass a certain quantity of water from a tank A to a receptacle B; if there is

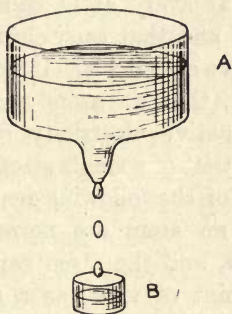


FIG. 27.

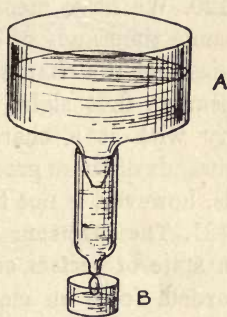


FIG. 28.

nothing between the tank and the receptacle, as shown in Fig. 27, then it is evident that every drop of water that arrives at B must pass bodily across the intervening space. Similarly, in order to pass a current of electricity between two points in a vacuum, it is necessary that the electrons must be made to pass bodily through the aether from the one point to the other.

119. On the other hand, if there is a pipe connecting A to B, as shown in Fig. 28, and if this pipe is previously filled with water, then it is evident that although every drop of water which passes out of one end of the pipe into the receptacle is replaced by another drop of water

entering the other end of the pipe from the tank, yet it is not necessary for each drop to traverse the length of the pipe. Similarly in the case of an electric circuit, on account of the presence of a large number of loose electrons in the intervening spaces between the atoms forming a conductor, a current of electricity can be passed through it by piling up the electrons at one end, and thus forcing a similar number of electrons out at the other end of the conductor.

120. We have mentioned that every atom consists of some thousands of electrons, and that each electron carries with it a charge of negative electricity. It would appear at first sight, therefore, that an atom should carry with it a charge of negative electricity some thousands of times greater than that of a single electron. This, however, is not the case, for the following reason.

121. **The electrons forming an atom are normally in a state of perfect equilibrium,** and the atom can be regarded, from an electrical point of view, as a self-contained system in which all the electromagnetic and electrostatic lines of force are within its outer surface. Thus the passage of an atom through space, or the addition of an atom to a conductor, causes no disturbance of the electrical equilibrium of surrounding atoms or electrons, and therefore causes no electrical phenomena.

122. If, however, one or more electrons be removed from an atom, then the internal electrical balance is destroyed, and lines of force are set up in the aether surrounding the atom. These lines of force tend to pull any available electrons into the atom to restore its electrical equilibrium. The passage of an atom in this condition through space, or its addition to a conductor, will cause a disturbance of the electrical equi-



librium of other atoms or electrons, and thus create electrical phenomena.

123. When an atom has been robbed of one or more of its normal complement of electrons it is known as an "Ion," and the force it exerts in trying to absorb any available electrons to restore its equilibrium, and also the force exerted by an electron in trying to become absorbed by an ion, is known as "Electromotive Force," and is measured in Volts.

124. Let us suppose now that we form a broken electrical circuit by bending a conductor, as shown by ABC in Fig. 29, so that the two ends A and C are insulated from one another by an air space. Assuming

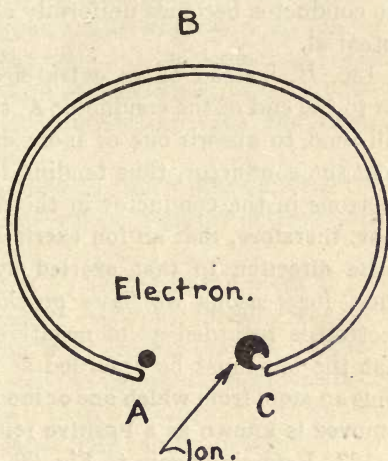


FIG. 29.

that all the atoms and loose electrons forming the conductor are complete, the conductor will be in a state of electrical equilibrium, and consequently there will be no E.M.F. exerted between the points A and C.

125. If, however, by some means we insert an extra electron into the end A, it is clear from the foregoing explanations that this extra electron will tend to push all the other loose electrons, distributed along the conductor, **in the direction ABC**, but since the end of

the conductor at C is insulated, no actual displacement of electrons can take place, and therefore no current will flow through the conductor. All the loose electrons distributed along the conductor being, so to speak, in contact with one another, the force exerted by the extra electron at the point A is felt equally by all the loose electrons throughout the conductor; in other words, the conductor becomes uniformly charged to a negative potential.

126. If, instead of an extra electron, we attach an ion to the end of the conductor A, then it is clear that it will tend to absorb one or more of the loose electrons from the conductor, thus tending to draw all the other electrons in the conductor in the direction CBA. **It is clear, therefore, that an ion exerts an E.M.F. in the opposite direction to that exerted by an electron.** And since, for reasons we have previously explained, the electron is regarded as of negative polarity, it follows that the ion must be regarded as of positive polarity. **Thus an atom from which one or more electrons have been removed is known as a Positive Ion.**

127. Referring again to Fig. 29, it is easy to see that if we attach an extra electron to the end A of the conductor and a positive ion to the end C, the loose electrons permeating the conductor will be actually displaced in the direction ABC, which, as explained in paragraph 114, can be regarded as a flow of current in the direction CBA.

128. Like charges repel one another, and unlike charges attract one another. Therefore, whereas an electron will be repelled from a negatively charged body and attracted to a positively charged body, a positive ion will be attracted to a negatively charged body and repelled from one positively charged.

129. All substances offer a certain amount of resistance to the passage of electrons through them ; those that offer a very small resistance are known as conductors, and those that offer a very high resistance are known as insulators. Whatever this resistance may be, it requires a certain E.M.F. to force a given number of electrons per second through a substance. On the other hand, a perfect vacuum offers no resistance to the passage of electrons. But whereas a conductor is already supplied with plenty of loose electrons wherewith to communicate an electric pressure from one end of the conductor to the other, no such electrons are available in a vacuum.

130. Therefore, in order to pass a current of electricity through a vacuum, some source of supply of free electrons must be provided.

131. If a metal wire be heated to the point of incandescence, the clusters of electrons forming the atoms on the surface of the wire are apparently broken up, or at all events loosened, and thus the electrons become available for carrying a charge of electricity to any other conductor **towards which they can be directed.**

132. But, in addition to supplying the necessary number of electrons to carry the required current through a vacuum, it is also necessary to create a tendency for the electrons to move away from their place of origin. This can be accomplished by applying an electromotive force between the source of the electrons and the point in the vacuum to which they are to be directed, **such that the point of arrival is at a positive potential relatively to the source.**

133. Thus, if two metal plates be placed in a vacuum, one of which is rendered incandescent to give a supply

of electrons, and if an E.M.F. is applied across the two plates **in such a way that the cold plate is positively charged**, a number of electrons will be attracted to the cold plate, carrying with them a charge of negative electricity.

134. Thus the space between the two plates becomes conductive, **but only in one direction**, because, since the electrons are negative and are liberated from the hot plate, only negative electricity can pass from the hot plate to the cold plate. This, in effect, is the same as a flow of positive electricity from the cold plate to the hot plate.



## THE FLEMING VALVE

135. THE phenomenon explained in the preceding paragraphs was first applied to Wireless Telegraphy by Dr. J. A. Fleming. In its original form it was used as a means of rectifying the high-frequency oscillations produced in a receiver by incoming signals, and in this form is known as the Fleming Valve.

136. Later developments of the valve have made it useful in other directions, as indicated in paragraphs 103 to 106, but a thorough comprehension of its characteristics in its simplest form will make it easier to follow the explanation of these later developments.

137. An illustration of the Fleming Valve is shown in Fig. 30. It consists of a metal or carbon filament (F) and a metal cylinder (S) (usually called the sheath) surrounding the filament, the filament thus forming the cathode and the sheath the anode of the valve. These two electrodes are enclosed in a glass bulb (B) similar in shape and appearance to an electric light bulb, which is highly exhausted.

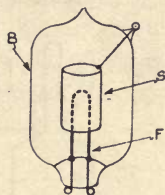


FIG. 30.

138. Another form of the Fleming Valve is shown in Fig. 31, in which the sheath consists of a flat metal



plate supported near the filament but not surrounding it. Or, again, the sheath may take the form of a coil

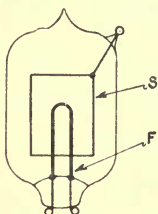


FIG. 31.

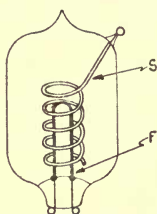


FIG. 32.

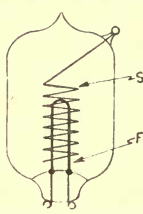


FIG. 33.

of wire or a wire zigzag, as shown in Figs. 32 and 33. Whichever form the valve takes its action is the same, although its characteristics may be slightly modified.

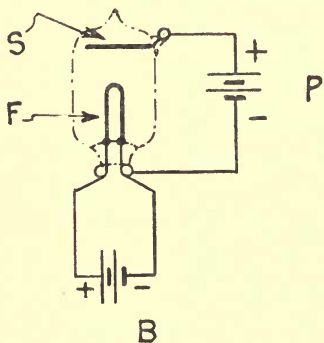


FIG. 34.

139. If, then, one of these electrodes be rendered incandescent by heating it to a suitable temperature, electrons will be liberated from its surface as described in paragraph 133, and the electrons being of negative polarity can be attracted to the sheath by charging the latter electrically to a

positive polarity relatively to the filament (*vide* paragraph 128).

140. In the Fleming Valve one electrode is heated by making it, as we have shown, in the form of a filament through which a current can be passed, as illustrated

in Fig. 34, from a battery (B). The sheath can be positively charged relatively to the filament by connecting the positive terminal of another battery (P) to the cold electrode or "sheath," and the negative terminal to the hot electrode or filament.

141. It will be observed that under these conditions a current will flow from the battery P through the circuit PSF. It should be noted, however, that this current is not flowing from the battery B, which is merely supplying current to the filament to maintain it in an incandescent state, but from the battery P. Exactly the same results would be obtained if the filament could be heated by other means and the battery B dispensed with.

142. Although the valve can be regarded as a conductor of electricity, it has been found that in several respects it does not act as an ordinary conductor, such as a metal wire, but that it has several distinct peculiarities. Its value as a detector of wireless signals depends upon making full use of these abnormal characteristics.

### CHARACTERISTICS OF THE FLEMING VALVE

143. The characteristics of a valve can best be studied by plotting a curve showing the relationship between the voltage applied to the sheath and the current which will flow through the valve.

144. To obtain this curve experimentally, we should set up a circuit consisting of a source of E.M.F. which can be varied to any required value, connected between the sheath and filament of a valve in series with a current-measuring instrument.

145. Such a circuit is shown diagrammatically in Fig. 35, where P is a potentiometer connected in such a way that the potential of the sheath S, with respect to the filament F, can be varied between +10 volts and -10 volts. The current flowing through the valve is measured by an ammeter A, and the voltage between the filament and the sheath can be measured either by connecting a voltmeter across the valve or by calibrating the potentiometer P.

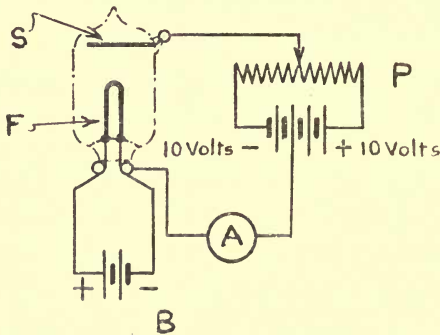


FIG. 35.

146. If, in the circuit under consideration, the valve behaved like an ordinary conductor, and if its resistance and that of the external circuit remained constant, then the current flowing through the circuit as indicated by the ammeter would vary in proportion to the E.M.F. of the sheath. The characteristic curve would therefore take the form of a straight line, as shown in Fig. 36.

147. But for reasons we have already explained, no current can flow through the valve when the potential of the sheath is negative to the filament. If this were the only limitation, then the current flowing through the

valve would still follow a straight line law, but would fall to zero at zero potential, and would remain zero no matter what negative potential were applied to the sheath.

148. As a matter of fact, although the frictional resistance of a vacuum to the passage of electrons is zero, the amount of **current which can be passed through the valve is limited**, as it depends upon the rate at which the electrons can be transferred from the filament to the sheath.

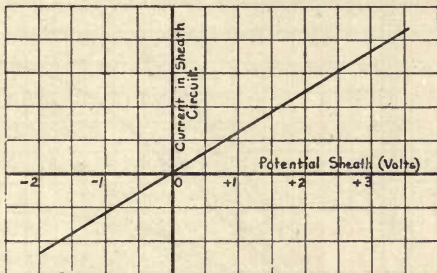


FIG. 36.

149. The student must not confuse the speed at which the electrons travel with the rate at which they are transferred. By the latter term is meant the number of electrons per second which leave the filament, assuming that they all arrive at the sheath. And as will be seen by referring to paragraph 114, it is on this rate of transfer of electrons that the value of the current flowing through the valve will depend.

150. If a series of readings be taken of the current which will flow through a valve for different E.M.F.'s applied to the sheath and the results plotted, it will be found that the curve takes a form similar to that shown

in Fig. 37, from a study of which several prominent points can be noted.

151. In the first place, it will be seen that when the potential of the sheath reaches about +7 volts, any further increase in the potential causes practically no increase in the current flowing through the valve. This

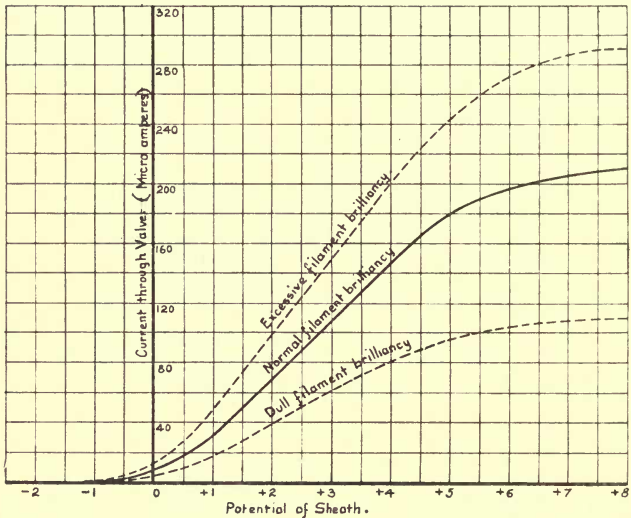


FIG. 37.

potential is known as the **saturation point of the valve**, and the maximum current which will flow through the valve is known as the **saturation current**. The actual value of this potential and that of the maximum current which will flow through the valve depends upon the size of the filament, its brilliancy, and the material of which it is made.

152. This saturating property of the valve is due



to the fact that **only a definite number of electrons are liberated from a given area of hot surface of any particular metal at a given temperature.** Since each electron carries a definite quantity of electricity, the current which can pass through the valve is also limited.

153. The higher the temperature of the metal, the greater the number of electrons liberated per unit area of surface, so that this maximum current for any particular valve can be increased or decreased by increasing or decreasing the brilliancy of the filament. To illustrate this we have indicated by dotted lines in Fig. 37 the current curves of the same valve, with the filament burning at different degrees of brilliancy.

154. The second important point to notice is that the **rate of increase** in the current flowing through the valve as the potential is increased from 0 volt to 8 volts, as indicated by the steepness of the slope of the curve, is not uniform. The rate of increase in the current is greatest between about +1 volt and +4 volts, and gets rapidly less as it is either decreased or increased beyond these limits. From this it follows that any given variation in the potential of the sheath between 0 and 1 volt, or between 4 and 6 volts, will cause a smaller change in the current flowing through the circuit than a corresponding variation in the potential of the sheath anywhere between 1 and 4 volts.

155. This effect is due partly to the drop in the potential along the filament, which, as we shall show later, results in the sheath being always at a different potential to different points on the filament, and partly to what is known as the **space charge.**

156. The third point to notice is that a certain amount of current flows through the valve when the sheath is

charged, even as much as one volt, negatively to the filament. At first sight this fact appears to be in contradiction to the principles already explained, but the reason is as follows.

157. When the filament is heated to a high state of incandescence, some of the electrons liberated from the surface are actually thrown off on to the sheath, so that without any attractive effort on the part of the latter a current will flow through the valve so long as the filament remains incandescent.

158. In order to stop all flow of electricity through the valve when the sheath is connected through some outside circuit to the filament, the sheath must be charged negatively, so that it is necessary to include in that circuit some source of E.M.F. by means of which the potential of the sheath can be adjusted to a value of about  $-1$  volt.

### THE SPACE CHARGE

159. When the sheath of the valve becomes positively charged relatively to the filament, the space between the filament and the sheath is filled with a cloud of negative electrons, which, being of the same polarity, tend to repel one another. Those electrons which happen to be nearest to the sheath are consequently not only being attracted by the positive charge on the latter, but are also being repelled towards the sheath by the negative electrons behind them, with the result that the speed at which they travel is increased. Those electrons which are farther away from the sheath, however, have not only got fewer electrons behind them to push them towards the sheath, but they have also electrons in front of them which are tending to push them back

towards the filament, with the result that they travel at a slower speed.

160. The effect of this is to choke back the stream of electrons, and prevent their free passage from the filament to the sheath.

### APPLICATION OF THE FLEMING VALVE TO RECEIVER CIRCUITS

161. These characteristics of the Fleming Valve can be usefully employed in connection with a Wireless Telegraph Receiver for the purpose of rectifying the oscillations set up in the receiver circuits by the incoming signals.

162. Let us take the case of a single circuit receiver, as illustrated in Fig. 38, consisting of an inductance connected in series with an aerial. When high-frequency oscillations are set up in the inductance by the incoming signal, they will cause a corresponding variation in the potential across the inductance. If we connect the

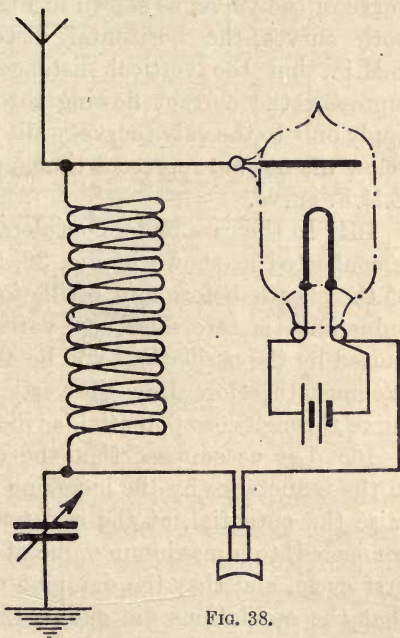


FIG. 38.

sheath of the valve to one end and the filament to the other end of this inductance, it follows that the potential of the sheath with respect to the filament will vary at radio frequency from a positive value at one moment to a negative value at the next moment.

163. In order to see at a glance what effect this variation of the potential of the sheath will have on the current flowing through the valve circuit, the curve illustrating the variation of the potential with regard to time can be plotted on the same diagram as the current curve of the valve, as shown in Fig. 39. In the case of both curves the horizontal distances represent the E.M.F., but the vertical distances **above the normal** represent the current flowing through the valve, and apply only to the valve curve, while the vertical distances **below the normal** represent time, and apply only to the E.M.F. curve.

164. In the case under consideration where the valve is connected as shown in Fig. 38, the normal potential of the sheath before any oscillations are set up in the inductance is zero, and any variation of the E.M.F. caused by the oscillations will be above and below zero. We must therefore draw the vertical axis of the E.M.F. curve through zero potential, as illustrated in Fig. 39.

165. Let us suppose that the oscillations produced in the inductance by the incoming signal are such as to raise the potential, at the end to which the sheath is connected, to a maximum value of two volts during the first cycle, and that the damping of the circuit is such that the oscillations die out in three complete cycles. We can illustrate these conditions by plotting an E.M.F. curve, as shown in Fig. 39, along the axis of time.

166. As a matter of fact, if the receiver is in tune with

the wave-length of the incoming signals, the oscillations induced in the receiver circuits would actually grow in amplitude during the first few cycles (*vide* paragraph 34), before they begin to die down as a result of the absorption of energy in the receiver. Also the total length of

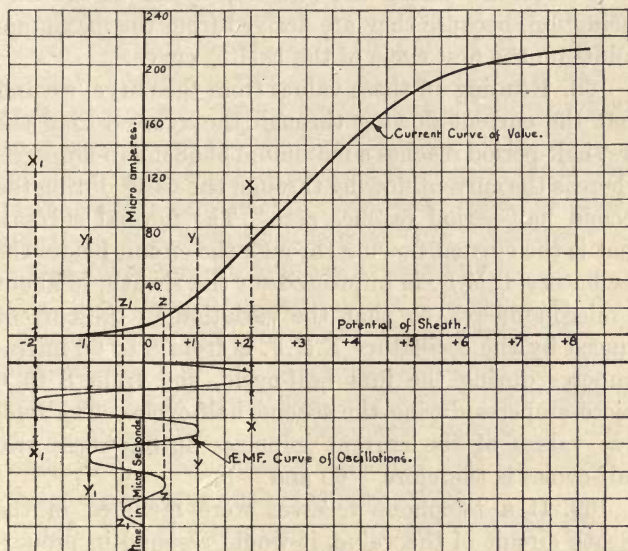


FIG. 39.

the train of oscillations would be considerably more than the three cycles illustrated. It will serve our purpose for the present, however, and simplify the diagram if we show only three cycles, and assume that the maximum positive value generated during the first half of each cycle is equal to the maximum negative value reached during the second half of that cycle.

167. By drawing a line from any point on the E.M.F.



curve parallel with the axis of time so that it intersects the valve current curve, we can read off the value of the current corresponding to the E.M.F. at that moment.

Thus the points at which the lines  $XX$  and  $X_1X_1$  intersect the current curve indicate the maximum values of the current during the two half-cycles of the first oscillation, because they are derived from the maximum points on the first cycle of the E.M.F. curve.

168. Reading off these values from the curve, we find that the current flowing through the valve during the first half-period reaches a maximum of 68 micro-amperes, whereas the current flowing through the valve during the second half-period reaches zero. The normal current, that is the current flowing through the circuit before the oscillatory E.M.F. is impressed on the sheath, is about 8 micro-amperes, so that the variation in the current caused by the oscillatory E.M.F. is from 8 to 68 micro-amperes during the first half-cycle, and from 8 to 0 micro-amperes during the second half-cycle. The relative values of the current impulses during these two half-cycles is therefore +60 and -8.

169. If a telephone receiver were included in the sheath circuit of the valve, it would respond in proportion to the **numerical difference between the positive and negative impulses**. By "positive impulse" we mean an increase in the current, and by "negative impulse" we mean a decrease in the current.

#### EFFICIENCY OF RECTIFICATION

170. In the explanations given in paragraphs 11 to 29 of the action of the reservoir condenser in accumulating unidirectional radio-frequency impulses from a

rectifier, and delivering them to the telephones in the form of a comparatively steady current, we assumed that the impulses were entirely unidirectional.

171. In the case under consideration, however, although the flow of current resulting from the oscillatory E.M.F. applied to the sheath is always in the same direction, the variation in the current is not unidirectional. That is to say, while an increase in the normal current is caused by the first half-oscillation, a decrease in this current is caused by the second half-oscillation. It is easy to see that in these circumstances, since the variations are occurring at radio frequency, **the increase in the voltage of a reservoir condenser would be proportional to the difference between the "positive" and "negative" current impulses flowing into it.**

172. If, then, we connect a pair of telephones with or without a reservoir condenser (*vide* paragraph 28) in the sheath circuit of the valve, as shown in Fig. 38, the strength of the signal produced in the telephones will be in proportion to the difference between 60 and 8, which is 52. For simplicity, we may term this difference **the effective value of the rectified current.**

173. By the same process we can find the effective value of the rectified current in the case of the second and third oscillations applied to the grid, which, owing to the damping of the circuit, are each of smaller amplitude than the last. Thus, in Fig. 39 the points at which the lines  $YY$ ,  $Y_1Y_1$  and  $ZZ$ ,  $Z_1Z_1$  intersect the current curve indicate the maximum values of the positive and negative impulses during the second and third cycles.

174. Reading off these values from the curve we get the following results, which may be tabulated for the sake of easy comparison thus :

	Positive Impulse.	Negative Impulse.	Effective Value.
First Cycle . .	68 - 8 = 60	0 - 8 = - 8	60 - 8 = 52
Second Cycle . .	30 - 8 = 22	0 - 8 = - 8	22 - 8 = 14
Third Cycle . .	12 - 8 = 4	4 - 8 = - 4	4 - 4 = 0

175. These figures reveal a fact of considerable importance, namely, that **the efficiency of the valve as a rectifier falls off very rapidly as the amplitude of the received oscillations is reduced**, and that for very feeble oscillations the valve does not rectify at all.

176. If we take the ratio of the effective value of the rectified current to the variation in the E.M.F. (*i.e.* the amplitude of the oscillation) as the measure of the efficiency of the valve as a rectifier, we get the following results for the three successively weaker oscillations shown in the diagram :

**First Cycle.** Amplitude of oscillation = 2 volts.  
 Effective value of rectified current = 52.  
 $\therefore$  Efficiency of rectification  $\frac{52}{2} = 26$ .

**Second Cycle.** Amplitude of oscillation = 1 volt.  
 Effective value of rectified current = 14.  
 $\therefore$  Efficiency of rectification  $\frac{14}{1} = 14$ .

**Third Cycle.** Amplitude of oscillation = .3.  
 Effective value of rectified current = 0.  
 $\therefore$  Efficiency of rectification  $\frac{0}{.3} = 0$ .

It is important that we should understand clearly why this rapid falling off in the rectifying property of the valve occurs.

177. In the first place, it will be noted that the positive half of the first oscillation carries the potential of the valve sheath to **the steepest part of the curve**, that is to say, to that part of the curve where a given variation in the potential of the sheath causes the greatest increase in the current; on the other hand, the positive halves of the second and third oscillations only carry the potential of the sheath to a comparatively flat part of the curve where a given variation in the potential of the sheath causes a very much smaller increase in the current. If this were the only consideration, it would obviously be an advantage to work on the steepest part of the curve.

178. But, in the second place, it will be noticed that since the effective value of the rectified current depends upon the difference between the positive and negative impulses, it is important not only that we get the greatest change in the current for a given variation of E.M.F., but also **that we get the greatest difference in the change of current due to a positive E.M.F. impulse and that due to a negative E.M.F. impulse.** This consideration, therefore, makes it desirable to work at that point where there is the greatest rate of change in the slope of the curve. This point occurs somewhere on the bend of the curve and can best be found by experiment.

179. To demonstrate these points more clearly, let us try the effect of **raising the potential of the sheath to a steady initial value** so that the variable E.M.F. produced by the incoming signal is superimposed on this steady E.M.F.

This can be accomplished by connecting a potentiometer in series with the telephones as shown in Fig. 40, by means of which the initial potential of the sheath

can be raised to any desired positive value up to, say, 4 volts.

180. To begin with, let us raise the initial potential to  $\cdot 5$  volt. The effect of this in the first place will be to cause a **steady current of about 12 micro-amperes to flow through the telephones**, thus increasing (or decreasing) the normal deflection of the diaphragm.

181. The incoming signal will raise the potential of the sheath to  $2\cdot 5$  volts during the first half-period, and reduce it to  $-1\cdot 5$  volts during the second half-period, and so on. These conditions can be conveniently illustrated by drawing the E.M.F. curve of the received oscillations about a normal drawn at  $\cdot 5$  volt as shown in Fig. 41, instead of at zero volts as was done in Fig. 39.

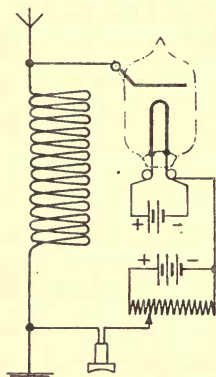


FIG. 40.

182. Reading off the values of the current as before, it will be seen that during the first half-period the current through the

telephones is increased from 12 micro-amperes to 90 micro-amperes, thus giving the telephones a **positive impulse of 78 micro-amperes**, while during the second half-period the current through the telephones is reduced from 12 micro-amperes to zero, thus giving the telephones a **negative impulse of 12 micro-amperes**. Therefore, the effective value of the rectified current is the difference between 78 and 12, which is 66, as compared with 52 obtained for the same oscillation when the normal sheath potential was adjusted to zero.



183. Similar readings taken for the second and third oscillations will show us that the effective values of the rectified current are 28 and 2 respectively, as compared with 14 and 0 obtained for the same oscillations when the normal sheath potential was adjusted to zero.

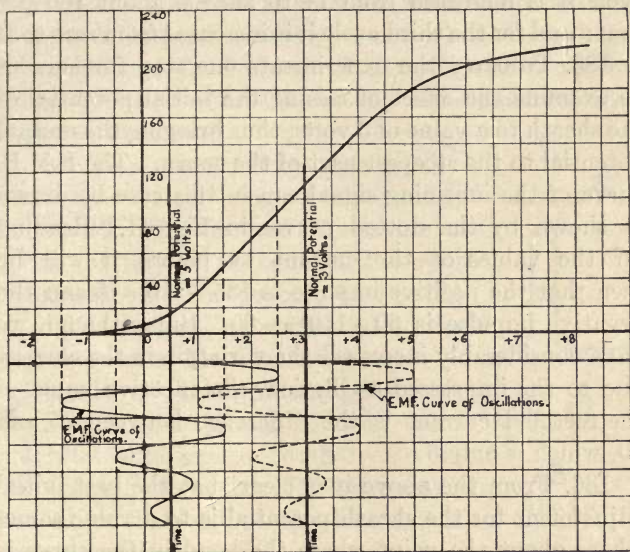


FIG. 41.

These results demonstrate clearly the advantage gained in the sensitiveness of a receiver if we include a potentiometer in the sheath circuit whereby the normal potential of the sheath may be regulated to the most efficient point on the valve curve.

184. It is also worth while noting that for weak signals the advantage of correctly adjusting the sheath potential is far more pronounced than in the case of

**strong signals.** Thus, comparing the effective value of the rectified currents obtained in the two experiments just described, we find that for the first cycle (representing a strong signal) the effective current is increased from 52 to 66, *i.e.* about 25 per cent; for the second cycle it is increased from 14 to 28, *i.e.* about 100 per cent; and for the third cycle it is increased from zero to 1.

185. To carry the experiments one step further, let us examine the effect of raising the initial potential of the sheath to a value of 3 volts, thus bringing the normal potential to the steepest part of the curve. The E.M.F. curve of the incoming signal can in this case be drawn as shown by the dotted curves in Fig. 41. Reading off the values of the current as before, it will be seen that the positive impulse is  $185 - 110 = 75$  and the negative impulse is  $30 - 110 = -80$ . But although we have considerably increased the variation in the current due to the impressed oscillation, the effective value of the rectified current is the difference between 75 and 80, which is only 5.

186. From the above it is clear that the best initial adjustment for the sheath potential is to a value somewhere about the point where the bend in the curve is sharpest. In practice this point can readily be found by sliding the potentiometer gradually while listening to the strength of the signals in the telephones.

#### THE DROP IN POTENTIAL ALONG THE FILAMENT

187. In the characteristic curve diagrams shown in Figs. 39 and 41 we have indicated definite values of the difference in potential between the sheath and the filament. These values would be true **for the whole**

of the filament only if there were no drop in potential along the filament. The only practicable means we have of heating the filament is by passing a current through it from some outside source of supply. To pass a current through the filament necessitates the creation of a **difference in potential between the two ends of the filament**, and since we can only connect the sheath to one point of the filament it follows that **no two points along the filament will be at the same potential with regard to the sheath.**

188. This point will be more readily understood by referring to the diagram in Fig. 42. In the case illustrated a 4-volt battery B is connected across the filament for the purpose of heating it, and the sheath is connected to the negative end of the filament.

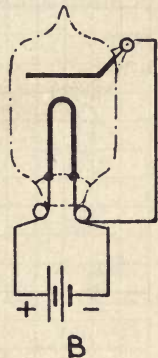


FIG. 42.

189. It is evident that under these conditions the sheath is at zero potential with regard to that end of the filament to which it is connected, but since that end of the filament is at a negative potential of 4 volts to the positive end, it follows that the sheath is also at a negative potential of 4 volts to the positive end of the filament.

190. When illustrating the characteristic curve of a valve, **the values of the potential of the sheath indicated are always those with respect to the negative end of the filament.** It follows that in the case of that particular valve the initial potential of the sheath at the best point for rectifying is about  $+0.5$  to the negative end of the filament and  $-3.5$  to the positive end of the filament.

191. It is convenient, in order to prevent any mis-

understanding regarding this point, to draw a thick line representing the filament immediately below the horizontal axis of the curve, in such a position that the actual potential across the filament, and also the potential of any point on the filament relatively to the sheath, is indicated by the abscissae. Thus if the curve illustrated in Fig. 41 represents the current flowing for different

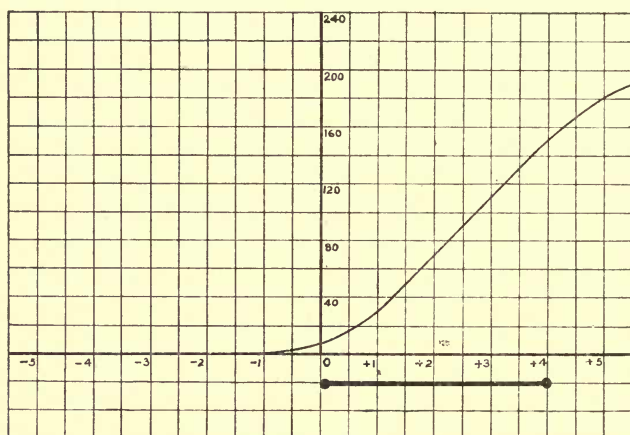


FIG. 43.

potentials of the sheath to the negative end of the filament, and if the drop in potential along the filament of the valve is 4 volts, we can conveniently indicate both of these points by drawing a thick line parallel to the horizontal axis between the values 0 and +4 volts as shown in Fig. 43.

192. The adjustment of the initial potential of the sheath to the best value can be accomplished, as we have already seen, by connecting a potentiometer in series with the valve circuit (*vide* Fig. 40).

193. A simpler way of obtaining the same result is to connect the potentiometer directly across the filament battery as shown in Fig. 44. It is easy to see that with this arrangement the potential of the sheath can be regulated to any value between 0 and +4 volts with respect to the negative end of the filament. Thus, in order to obtain an E.M.F. on the sheath of +.5 volt to the negative end of the filament, the point of connection to the potentiometer would be one-eighth of the length of the potentiometer distant from its negative end.

194. This is the method usually employed in all wireless telegraph receivers using the Fleming Valve as a rectifier, but a slight modification was found necessary to suit the circuits to any valve.

195. It was found, particularly in the case of valves fitted with Tungsten filaments which were burnt at a very high point of incandescence, that the best point for rectifying occurred at a negative potential of about .3 volt to the negative end of the filament.

196. With the arrangement shown in Fig. 44 it is not possible to get a negative potential on the sheath with regard to the negative end of the filament. To overcome this difficulty and at the same time to avoid the use of a separate potentiometer battery, a 6-volt battery can be used for lighting the 4-volt filament, and a resistance connected in series with the battery to reduce the E.M.F. across the filament.

197. Owing to the drop in potential across this

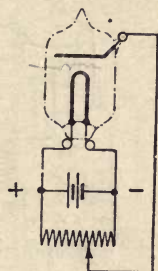


FIG. 44.



resistance when the filament current is passing through it, it is evident that there will be a difference in potential of 2 volts between the two ends of the resistance. **If the resistance is connected between the negative end of the battery and the filament** as shown by R in Fig. 45, then it follows that the negative end of the battery is at a negative potential of 2 volts to the negative end of the filament, so that if the sheath circuit were connected to the negative battery terminal instead of to the filament, the potential of the sheath would be  $-2$  volts to the negative end of the filament.

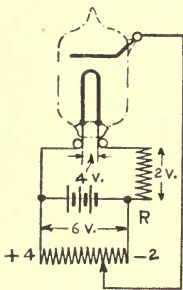


FIG. 45.

198. From this it is easy to see that if a potentiometer be connected across the 6-volt battery, and the connection of the sheath circuit brought to the sliding point on the potentiometer, that the potential of the sheath can be thereby adjusted to any desired value between the limits of  $-2$  volts and  $+4$  volts to the negative end of the filament.

In order to obtain this effect it is **essential that the series resistance is connected between the negative terminal of the battery and the filament.**

199. In Fig. 40 we illustrated how the Fleming Valve can be employed in connection with a Wireless Telegraph Receiver. Such a receiver is known as a "single circuit receiver," as it includes only one tuned circuit, namely, the aerial circuit.

Such a receiver is not very efficient, more especially for short wave-lengths, for the reason that the valve is connected across only a part of the total inductance in the aerial circuit, the rest of the inductance being

made up by the inductance of the aerial itself. For long wave-lengths, however, where the proportion of the added inductance (across which the valve is connected) is large compared with the inductance of the aerial, these connections will give good results and they have the advantage of being extremely simple.

200. For ordinary purposes the two-circuit receiver gives by far the best results. In this case the energy picked up by the aerial from the incoming signal is transferred to a second oscillatory circuit, called the secondary circuit, across the whole of which the valve can be connected, thus enabling full benefit to be drawn from the received energy.

201. A diagram of the connections of a two-circuit receiver is shown in Fig. 46. The aerial circuit consists, as before, of an aerial, a variable inductance known as the "aerial tuning inductance," and a variable condenser known as the "aerial tuning condenser." This circuit is tuned to the incoming signals and is inductively coupled to a secondary circuit.

202. The secondary circuit is a simple closed oscillatory circuit consisting of a fixed inductance and a variable condenser, and is also tuned to the incoming signals. The valve or detector circuit is connected across the secondary circuit as shown.

203. The use of the Fleming Valve as a rectifier of

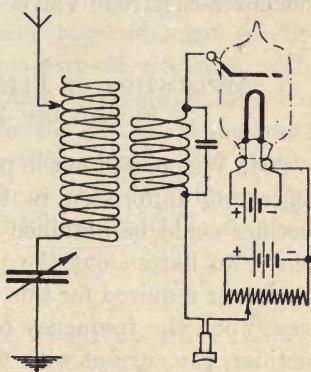


FIG. 46.

received oscillations has been largely superseded by the crystal detector, on account of the fact that the sensitiveness of the latter is for all practical purposes equal to that of the Fleming Valve while avoiding the inconvenience and cost of a filament battery. A thorough understanding of the principles of the Fleming Valve, however, will be of the greatest assistance to the student when we discuss the characteristics and application of the Three-Electrode Valve.

#### APPLICATION OF FLEMING VALVE TO LOW-FREQUENCY RECTIFICATION

204. We pointed out in paragraph 29 how any desired degree of uniformity in the current delivered by a rectifier could be obtained by using a big enough condenser to flatten out the peaks. The capacity of the condenser required for this purpose depends, as we have seen, upon the frequency of the E.M.F. applied to the rectifier, the current with which it has to deal, and the degree of uniformity required.

205. We shall explain later the necessity for generating current at a very high potential for "feeding" large power transmitting valves. In some cases continuous current at a potential of 10,000 volts or more is required, and there are many practical difficulties in the design and manufacture of a D.C. generator for this purpose, chiefly as regards the insulation of moving parts and the commutation of the current.

206. This problem of supply can be very much simplified by using an alternator to generate the necessary power at any convenient voltage. The E.M.F. of the alternator can then be transformed up to the re-

quired valve and rectified by a Fleming Valve specially designed to carry the necessary current.

207. The principles underlying the application of the Fleming Valve for this purpose are exactly the same as described in the foregoing chapters, except that the adjustment of the normal sheath potential is quite an unnecessary refinement. The construction of the valve is of course different, owing to the comparatively high value of the current which it is required to pass through the valve necessitating a very large filament for the generation of a sufficient quantity of electrons. The rectified current is fed to a large reservoir condenser of sufficient capacity to maintain the current in the transmitting valve circuit during the negative half of each alternator cycle without serious drop in voltage, thus flattening out the peaks and filling up the intervals of the rectified current.

## GENERAL CHARACTERISTICS OF THE THREE-ELECTRODE VALVE

208. IF a piece of metal gauze be interposed in the vacuum between the filament and the sheath of a Fleming Valve as illustrated in Fig. 47, electrons can still pass through the meshes of the gauze and be attracted to the sheath as before so long as the electrostatic field produced by the positive charge on the sheath reaches the filament. This field, however, can be neutralised by a negative field which would be created if the metal gauze

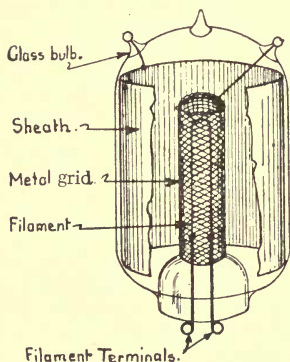


FIG. 47.

were charged negatively with regard to the filament. Thus if the metal gauze, which forms the third electrode and is usually termed **the grid**, be charged to a sufficiently high negative potential, not any of the field produced by a positive charge on the sheath can reach the filament, and therefore no electrons will be attracted to the sheath. The precise value of the negative potential necessary in any

created if the metal gauze were charged negatively with regard to the filament. Thus if the metal gauze, which forms the third electrode and is usually termed **the grid**, be charged to a sufficiently high negative potential, not any of the field produced by a positive charge on the sheath can reach the filament, and therefore no electrons will be attracted to the sheath. The precise value of the negative potential necessary in any



particular valve to stop entirely the flow of electrons will be discussed later, but for the moment it will be sufficient to note to what extent the flow of electrons is reduced for different degrees to which the grid is charged negatively, assuming that a constant positive charge is maintained on the sheath.

### EFFECT OF GRID POTENTIAL ON VALVE CURRENT

The effect of the grid potential on the flow of electrons from the filament to the sheath can easily be determined by setting up a circuit similar to that shown diagrammatically in Fig. 48.

209. It will be observed that the sheath S is maintained at a uniform potential relatively to the filament by the battery H. On the other hand, the potential of the grid G with regard to the filament can be varied by moving the sliding contact along the potentiometer resistance, from a certain maximum negative potential to zero potential. The battery B is merely supplying current to the filament to maintain it in a state of incandescence.

210. It will be noted that with this arrangement we have two distinct electrical circuits through the valve. The one, known as the **sheath circuit**, is formed by the sheath S, the battery H, and the filament F, and since the sheath is so connected as to be positively charged

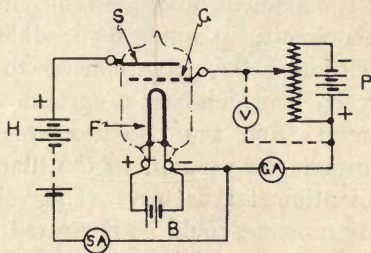


FIG. 48.

with regard to the filament, so long as electrons can pass from the filament to the sheath a current will flow in this circuit from the battery H to the sheath S, through the vacuum to the filament F, and back to the battery H. If we connect a milliammeter SA in this circuit we can observe the value of the current flowing at any moment.

211. The other, **known as the grid circuit**, is formed by the grid G, the potentiometer P, and the filament F. So long as the grid is at a negative potential relatively to the filament no appreciable current can pass through this circuit. It would be possible, however, by suitably connecting the potentiometer to charge the grid positively, in which case a current would flow in the grid circuit from the potentiometer battery to the grid, through the vacuum to the filament, and back to the potentiometer battery. The value of this current at any moment could be measured by connecting another milliammeter GA in series with the grid circuit as shown in the diagram.

212. The action of the valve is more easily understood by taking one thing at a time, and as the point we are studying at the moment is the effect of the grid potential on the flow of electrons from the filament to the sheath, it will be less confusing if we assume that the conditions are such that no electrons can pass to the grid, and therefore that no current can flow in the grid circuit.

213. In the circuit illustrated in Fig. 48 the potential of the grid relatively to the filament can be measured by connecting a voltmeter V across the potentiometer as shown by the dotted lines in the diagram. A simpler way is to calibrate the potentiometer resistance so that

the position of the sliding contact indicates the potential, in which case the voltmeter V can be dispensed with.

214. If readings be taken of the **current flowing in the sheath circuit** as indicated by the milliammeter SA for different potentials of the grid, as obtained by varying the adjustment of the potentiometer P, these results can be plotted and the curve thus obtained will be found to take the general form shown in Fig. 49. Comparing this curve with the curve of the Fleming Valve shown in Fig. 37, it will

be observed that there is very little difference between the two as regards their shape, but it must be remembered that whereas the Fleming Valve curve illustrated

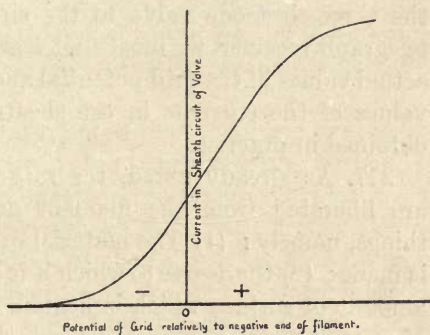


FIG. 49.

in Fig. 37 shows the relationship between the **potential applied to the sheath** and the current flowing through the sheath circuit, the curve illustrated in Fig. 49 shows the relationship between the **potential applied to the grid** and the current flowing through the sheath circuit.

215. In Fig. 49 we have not indicated either the values of the current flowing through the sheath circuit or the corresponding values of the grid potential. Our reason for omitting to do this is that the actual values of these two factors depend upon many circumstances which we have not yet considered. Whatever these

values may be, the general form of the curve will be the same in all cases. The curve shows that as the negative potential of the grid is reduced the current in the sheath circuit increases comparatively slowly up to a certain critical value where the first bend in the curve occurs. After this point the increase in the current is comparatively rapid until the saturation point is reached where the second bend in the curve occurs.

216. Before we discuss the best methods of applying the three-electrode valve to the circuits of a wireless telegraph receiver, we must first learn something of the actual values of the grid potential and the corresponding values of the currents in the sheath and grid circuits obtained in practice.

217. As already noted, the rate at which electrons are liberated from the filament depends upon three things, namely: (1) The material of which the filament is made; (2) the degree to which it is heated; and (3) the amount of surface which is heated. Since the amount of current which can pass through the vacuum depends upon the flow of electrons, it follows that the maximum value of the current which can pass through the valve depends upon the three factors mentioned above.

218. The metal of which that filament is made and the size of the filament is fixed by the manufacturers according to the nature of the work for which the valve is intended. It is sufficient for the purpose we have in view, therefore, if we take a typical example of a three-electrode valve designed for receiving circuits and show to what extent its characteristics can be controlled by outside means without interfering with the design and construction of the valve, and also demonstrate what are the most favourable conditions under which the valve

can be used for the several purposes enumerated in paragraphs 103 to 106.

219. Referring again to the circuits illustrated in Fig. 48, it will be observed that there are three factors which can be controlled outside the valve itself, namely :

(1) The value of the positive potential applied to the sheath by the battery H.

(2) The brilliancy of the filament, which can be varied by including an adjustable resistance in series with it.

(3) The potential applied to the grid by the potentiometer P, which can be varied by means of the sliding contact.

220. We have also noted that there are two distinct circuits through the valve along which a current can flow, namely, the sheath circuit and the grid circuit. The current flowing through the sheath circuit is limited by the rate at which electrons flow from the filament to the sheath, and similarly the current flowing through the grid circuit is limited by the rate at which electrons flow from the same filament to the grid. It follows, therefore, that **the total current flowing through the valve, as represented by the total flow of electrons from the filament, may be divided into two parts, one part passing to the grid and thence through the grid circuit, and the other part passing through the meshes of the grid to the sheath and thence through the sheath circuit. The sum of the grid and sheath currents obviously represents the total current flowing through the valve.**

221. Before we examine the relative proportions of these two currents, let us first study the effect of the three controllable factors mentioned in paragraph 219 on the total current flowing through the valve for



different grid potentials, that is, on the total electron emission from the filament.

To do this we will first assume that the voltage of the sheath battery H, Fig. 45, is fixed at some predetermined value, and examine the effect of varying the brilliancy of the filament.

#### EFFECT OF FILAMENT BRILLIANCY ON VALVE CURVES

222. In Fig. 50 we show the curves obtained from a typical small-sized receiving valve with the filament burning at three different degrees of brilliancy. In all three cases the sheath potential is maintained at a constant value of about 50 volts, and the grid potential, as indicated by the abscissae, is varied between values of  $-2$  volts and  $+6$  volts relatively to the negative end of the filament.

223. The middle one of the three curves shows the values of the total current passing through the vacuum when the filament is burning at normal brilliancy, the current passing through the filament being about  $.4$  ampere; the top curve shows the values of the current when the filament is burning at a somewhat excessive brilliancy, the current passing through the filament in this case being about  $.45$  ampere; the bottom curve shows the values of the current when the filament is burning below normal brilliancy, the current passing through the filament being about  $.35$  ampere.

224. It will be noticed that the **chief difference in the three cases is in the steepness of the slope of the curves and in the maximum current which can be passed through the valve.** There is, however, another difference which, although not nearly so pronounced nor so apparent from

a study of the curves, becomes perceptible in practice when the valve is used as a rectifier. We refer to the sharpness of the bend in the curve.

225. At first sight it would appear that the greater the brilliancy of the filament the sharper the bend in

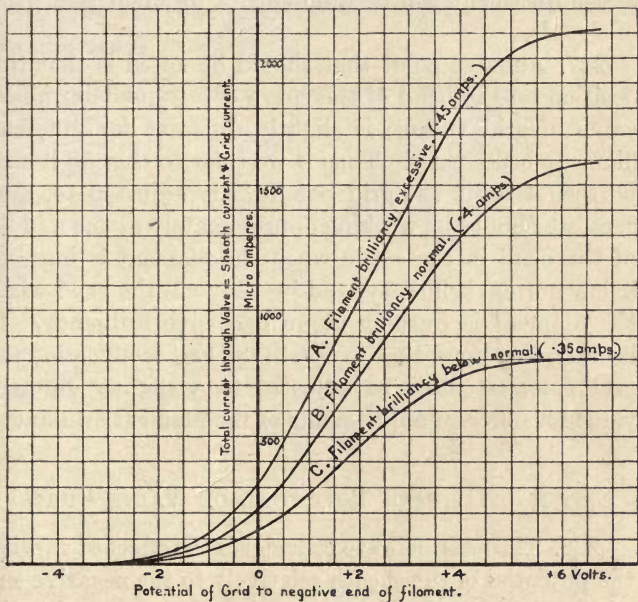


FIG. 50.

the curve. This, however, is not the case, and it will be found, by very minute and careful examination, that the sharpest bend is obtained when the filament is burning at somewhere about normal brilliancy. With some valves the sharpest bend is obtained when the filament is even below normal brilliancy. This feature is more pronounced in some types of valve than in

others, but it is always present to a greater or less degree.

226. Thus it will be found that **there is a best adjustment for the brilliancy of the filament to obtain maximum rectification for a given strength of signal**, and that this best adjustment will be different for different strengths of signals.

227. Another point that should be noted is that the position on the bend of the curve of any predetermined value of grid voltage is slightly different for different filament brilliancies. Thus if we refer to Fig. 50 it will be seen that if the grid potential is adjusted to, say, zero, we should be working approximately at the middle of the bend in the curve when the filament is burning below normal brilliancy, and just beyond the bend when the filament is burning at an excessive brilliancy. It is clear, therefore, that **to obtain the best rectification the grid potential must be adjusted to a slightly different value for different adjustments of the filament brilliancy.**

#### EFFECT OF SHEATH POTENTIAL ON VALVE CURVES

228. The next point to consider is the effect of varying the potential of the sheath relatively to the negative end of the filament, that is to say, the effect of varying the E.M.F. of the battery H in the circuit illustrated in Fig. 48.

229. In Fig. 51 we show the curves obtained from the same valve as that from which the curves illustrated in Fig. 50 were taken, with three different potentials applied to the sheath. In all three cases **the filament is maintained at normal brilliancy** and the grid potential is varied between values of  $-4$  volts and  $+6$  volts. The

only difference in the conditions under which the valve was tested is therefore the value of the positive potential applied to the sheath, which, as indicated in the diagram against each curve, is 150 volts, 100 volts, and 50 volts respectively. It will be observed that the effect of applying a higher potential to the sheath is to shift the curve bodily to the left.

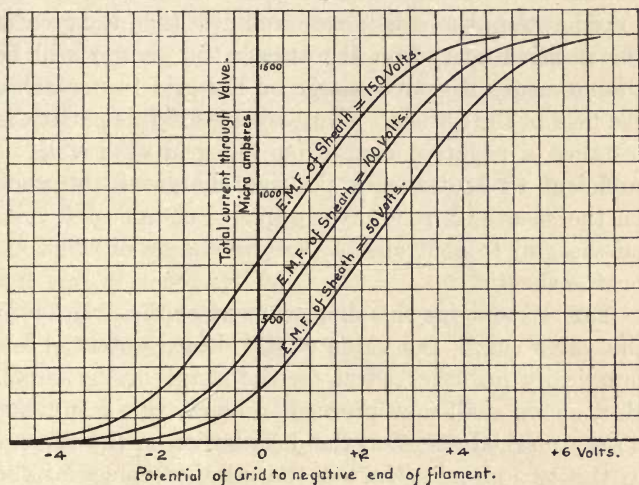


FIG. 51.

230. The reason for this is easily explained. The sheath potential would in all three cases be more than sufficient to overcome the space charge and attract all the available electrons from the filament to the sheath if it were not for the fact that its field, and therefore also its power to attract electrons, is neutralised by a negative charge on the grid. Since the strength of the field produced by a charged body at a given distance

from that body is directly proportional to the charge on the body, it is easy to see that the value of the negative charge on the grid necessary to neutralise entirely the effect of a given charge on the sheath will vary considerably according to the relative distances between the sheath and the filament and between the grid and the filament.

231. It is also clear that if, as in the case under consideration, these distances are fixed, then the greater the positive charge on the sheath the greater will be the necessary negative charge on the grid to neutralise the field of the former. Thus, whereas in this particular instance a negative charge on the grid of 2 volts is sufficient to neutralise a positive charge of 100 volts on the sheath, it requires a negative charge of 4 volts on the grid to neutralise a positive charge of 200 volts on the sheath.

232. Except for this displacement of the position of the valve curve, the value of the sheath potential has practically no other effect on the shape of the curve. But, as we shall now proceed to show, this result has a very marked effect on the distribution of the current in the two circuits, *i.e.* on the relative values of the currents in the grid and sheath circuits, and becomes a matter of considerable importance in the application of the valve to the several purposes we have in view.

#### DISTRIBUTION OF VALVE CURRENT BETWEEN GRID AND SHEATH CIRCUITS

233. In the curves illustrated in Figs. 50 and 51 we have plotted the values of the **total current flowing through the valve** against different values of grid poten-



tial. Our reason for doing this was to eliminate as far as possible all questions with which we were not immediately concerned. As already indicated in paragraph 220, all the electrons do not necessarily pass to the sheath, as some of them may fall on the grid, provided the latter is in a condition to receive them.

234. If some of the electrons do actually fall on the grid, and if there is a circuit from the grid to the filament, then it is clear that a current will flow in this grid circuit whose value will be proportional to the rate at which the electrons are received by the grid. It is obvious that in these circumstances the total current flowing through the valve will be divided, part flowing through the sheath circuit and part through the grid circuit. The question we are concerned with at the moment is the relative values of these two currents.

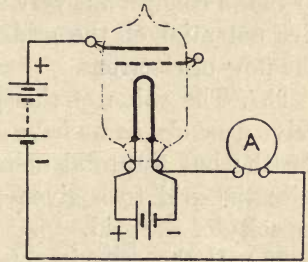


FIG. 52.

235. To prevent any misunderstanding, we will again take as an example the small type of receiving valve whose characteristics under various conditions we have studied in the preceding paragraphs. If, then, one of these valves be connected up as shown in Fig. 52, so that a battery H maintains the sheath at a positive potential of, say, 100 volts, and so that the grid is left **entirely disconnected and insulated from any part of the circuit**, it might be expected that the full saturation current would flow through the sheath circuit of the valve. This, however, is not the case, and for the following reason.

236. Some of the electrons, instead of passing through the meshes of the grid, impinge on the wires forming it. Since the grid is disconnected from the filament, it is unable to get rid of these electrons, with the result that **the grid becomes charged to a negative potential.** The effect of this, as we have already observed, is to reduce the flow of electrons from the filament to the sheath, **but so long as any electrons at all are flowing a certain number will always fall on the grid wires.** The greater the number of electrons which accumulate on the grid the higher the negative potential to which it is charged, so that a condition is very soon reached when the negative potential of the grid is sufficient to stop entirely the flow of electrons.

237. The value of this potential for any particular valve depends, as we have seen, upon the E.M.F. of the sheath; but the total number of electrons required to raise the grid to a given potential depends upon the capacity of the grid.

238. If the capacity of the grid were zero, then a single electron would charge it up to a high negative potential. On the other hand, if the capacity of the grid were 1 farad, then it would require  $10^{19}$  electrons to raise its potential by 1 volt, because  $10^{19}$  electrons are equivalent to 1 coulomb of electricity (*vide* paragraph 114), and 1 coulomb of electricity will raise the potential of a condenser having a capacity of 1 farad by 1 volt.

239. The actual capacity of the grid depends upon its total bulk and upon its proximity to the filament and sheath, just as the capacity of an aerial depends upon the size of the aerial and its proximity to the earth; but in any case its capacity is of an extremely small order, and consequently very few electrons are necessary to

raise its potential to the two or three volts necessary to stop all flow of electrons from the filament. Consequently the stoppage of the electron flow occurs almost instantaneously with the application of the positive potential to the sheath.

240. Suppose now that we connect the grid to the negative end of the filament, thus completing the grid circuit. By so doing we form a path for the electrons outside the valve, enabling any electrons which impinge on the grid to pass freely through this connector back to the filament. The effect of this is twofold. In the first place the flow of electrons through the grid circuit constitutes a grid current, and in the second place the potential of the grid is reduced to a value equal to the potential of that part of the filament to which it is connected.

241. The effect of raising the grid potential to zero value is to allow once more some of the field produced by the positive charge on the sheath to reach the filament, with the result that a certain number of electrons are attracted from the filament towards the sheath. In the case of the valve we are considering, when the filament is burning at normal brilliancy and the potential of the sheath is 100 volts, the number of electrons is equivalent to a current of about 400 micro-amperes, as indicated by the middle curve in Fig. 51.

242. For reasons we shall explain, practically all of these electrons pass through the meshes of the grid to the sheath, so that under these conditions **the value of the sheath current is 400 micro-amperes and the value of the grid current is practically zero.**

243. The explanation of this is that the electrons tend to travel through the vacuum along the lines of

force of the field which is attracting them. In the case we are considering the grid is at the same potential as the negative end of the filament, and therefore there are no lines of force connecting the wires of the grid to the negative end of the filament. Since all other points on the filament are necessarily at a different potential from the grid, there are of course lines of force connecting the wires of the grid to the rest of the filament. Owing to the direction of these lines, that

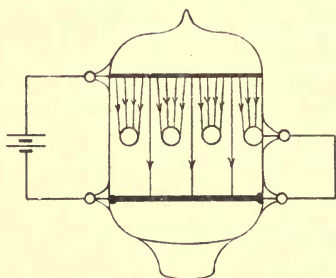


FIG. 53.

is to say, owing to the fact that the grid is negative to all other points on the filament, there is no force attracting the electrons. We may therefore neglect all except the negative end of the filament.

244. The only effective lines of force, there-

fore, which reach the filament emanate from the sheath, and consequently the electrons thus attracted from the filament pass along these lines of force directly to the sheath.

245. This point will be more clearly understood by referring to Fig. 53, where we have illustrated diagrammatically the distribution of the electrostatic field in the valve. For the sake of simplicity, we have assumed that there is no drop in potential along the filament, and therefore, since the grid is connected to the filament, the difference in potential between the grid and the whole of the filament is zero. It will be noticed that most of the lines of force produced by the sheath pass to the



wires of the grid. The reason for this is that the grid is at the same negative potential relatively to the sheath as the filament, and is much nearer than the filament to the sheath; a few lines, however, pass through the meshes of the grid to the filament, and it is along these lines of force that the electrons travel.

246. In Fig. 54 we have shown diagrammatically the distribution of the field under similar conditions, but allowing for the difference of potential along the filament, the grid being connected to the negative end of the filament. The arrows on the lines of force indicate the direction of the lines (which is opposite to the direction in which the negative electrons travel). Thus in the case illustrated in Fig. 51 the direction of all of the lines of force connecting the filament to the grid, due to the fact that the grid is at a negative potential to the positive end of the filament, is such that no electrons can travel along them from the filament to the grid (*vide* paragraph 244).

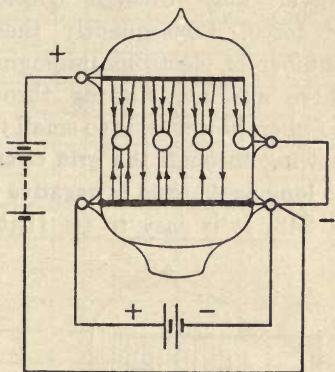


FIG. 54.

247. At first sight this may seem to disprove the explanation given in paragraph 236 of the charging up of the grid when the latter is insulated from the rest of the circuit. It must be remembered, however, that the electrons, though minutely small, nevertheless have a certain mass. Owing to their mass they will possess



the quality of momentum when travelling through space, and it is due to this momentum that they do not necessarily travel exactly along the line of force. A body moving through space always tends to travel in a straight line; thus, wherever a line of force deviates from a straight line (and the electrostatic field in a valve is always more or less distorted), the paths along which the electrons actually travel may diverge considerably from the lines of force. Consequently there are always a certain number of electrons impinging on the grid so long as there are any flowing through the vacuum. Their number, however, is so small that the equivalent current flowing through the grid circuit is practically negligible so long as the grid is negative to all parts of the filament.

248. It is easy to see that if the grid is raised to a

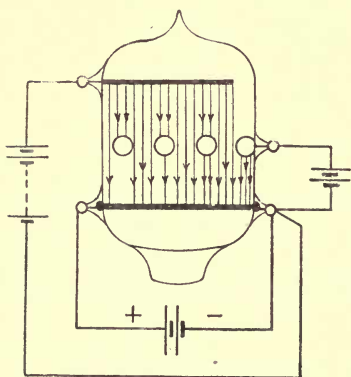


FIG. 55.

positive potential relatively to any part of the filament, a certain number of lines of force will be produced connecting the filament directly to the grid, the direction of which will be such as to enable electrons to travel along them from the filament to the grid, as shown in the simplified diagram in Fig. 55. It will be

seen that under these conditions, that is, when the grid is raised to a positive potential relatively to the filament, a flow of electrons will be induced from the filament to

the grid, resulting in a flow of current in the grid circuit of the valve.

249. In addition to creating a field of its own between the filament and the grid, the raising of the grid potential also increases the number of lines of force which leak past the meshes of the grid from the sheath to the

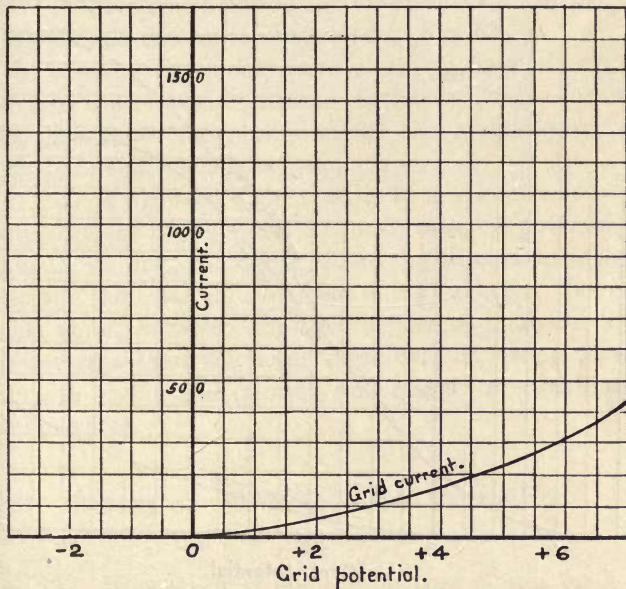


FIG. 56.

filament, thus increasing the flow of current in the sheath circuit of the valve. Unless the current through the valve be somewhere near the saturation point, the increase in the current through the sheath circuit is very large compared with the increase in current flowing through the grid circuit, due to a given rise in the potential of the latter.

250. If an ammeter be connected in series with the grid circuit, as shown by GA in Fig. 48, and if readings be taken of the current flowing through this circuit for various grid potentials and the results plotted, the curve will take the form shown in Fig. 56. The readings indicated by this curve were taken for the same valve

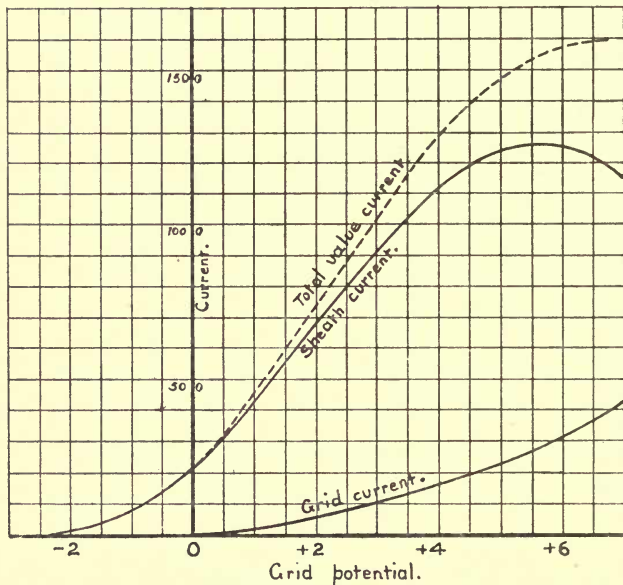


FIG. 57.

as used for the previous tests. The value of the sheath potential was maintained at 50 volts and that of the grid potential was varied from  $-2$  volts to  $+6$  volts, the brilliancy of the filament being normal. It will be noticed that until the grid potential reaches a value of  $+1$  volt the current in the grid circuit is practically negligible (*vide* paragraph 247),

but after that point it increases more and more rapidly.

251. In Fig. 51 we showed by a curve diagram the values of the total valve current obtained from the same valve, under exactly the same conditions; it is clear, therefore, that the curve of the sheath current will be the difference between the lower curve illustrated in Fig. 51 and the curve illustrated in Fig. 53.

To make the point quite clear we have shown in Fig. 57 the curves illustrating (1) the total valve current, (2) the sheath current, and (3) the grid current, all plotted on the same diagram.

252. It will be noticed that up to the point where the grid current is negligible, *i.e.* until the grid potential is about +1 volt, the curve of the sheath current follows that of the total valve current almost exactly. Beyond this point, however, the sheath current increases at a lower rate than the total valve current, owing to the growth of the grid current, and reaches a lower maximum value.

#### EFFECT OF THE MECHANICAL PROPORTIONS OF THE VALVE

253. Although it is not the purpose of this book to teach the student how to design valves, it is nevertheless desirable that he should have some knowledge of the effect of such factors as the size of the filament, the relative distances from the filament to the sheath and the filament to the grid, and the ratio of the thickness of the wires of which the grid is constructed to the space between the wires.

In the preceding paragraph we have limited our

investigations to one particular type of valve, but the conclusions we came to regarding the effect of the different electrical factors on the characteristic curve hold good for every type of valve. These effects, however, may be more or less modified according to the design of the valve and the purpose for which it is used.

### SIZE OF FILAMENT

254. The size of the filament regulates the total electron emission available. As we have seen, this can also be controlled by the brilliancy of the filament, but if a filament be used for any length of time at an excessive brightness it very soon disintegrates, and the life of the valve is reduced. On the other hand, the duller the filament the lower the electron emission for a given expenditure of energy in heating the filament. The curves illustrated in Fig. 50 show this point very clearly, where it will be seen that for a 30 per cent increase in the current passing through the filament, namely, from .35 ampere to .45 ampere, the maximum current which can pass through the valve is increased from about 800 micro-amperes to 2000 micro-amperes, or an increase of about 150 per cent. It is obvious that for the sake of efficiency the size of the filament should not be greater than is required for the purpose for which the valve is to be used.

255. In the case of receivers there is no object in using a valve having a greater current-carrying capacity than about 1500 micro-amperes. On the other hand, for transmitting purposes it may be desirable that the valve should carry as much as 300,000 micro-amperes (300 milliamperes) or more according to the power which it



is desired to deliver to the transmitting aerial. In this case the dimensions of the filament, *i.e.* its length and diameter, must be increased accordingly.

256. The following particulars, taken from three different types of valves, may be of some value as indicating broadly the proportions of the filaments met with in practice.

**No. 1** Valve, used for receiving purposes—power required to heat filament (normal brilliancy), .4 ampere at 5 volts = 2 watts.

**No. 2** Valve, used chiefly for receiving purposes, but also useful for small-powered transmitters up to 50 watts—power required to heat filament, 1.2 amperes at 5 volts = 6 watts.

**No. 3** Valve, used for transmitting purposes, and useful for powers up to .5 kw.—power required to heat filament, 8 amperes at 12 volts = 96 watts.

#### EFFECT OF GRID MESH AND DISTANCE OF GRID FROM FILAMENT ON VALVE CHARACTERISTICS

257. From the point of view of the person using a valve, the mesh of the grid or its distance from the filament are not matters of great importance. The effect of these factors, however, determines to a great extent the characteristics of the valve, and consequently affect the question of the suitability of a particular type of valve for a particular purpose. The whole question is one of such complexity that it would only confuse the student if we attempted to explain it at all fully in this book. It is quite sufficient for our purpose if we indicate very broadly the effect of varying the mesh of the grid and the effect of increasing or reducing its distance from

the filament, assuming that these variations are made within small limits. It would not, however, be safe to assume that the conclusions we may draw would be true for extreme cases.

258. If we take first of all the effect of opening the mesh of the grid, that is to say, of increasing the size of the holes in the grid fabric, it will easily be seen by referring again to Figs. 53, 54, and 55 that the greater the distance between the wires of the grid, **the greater will be the number of lines of force which reach the filament from the sheath** for a given grid potential and for a given sheath potential. An open-meshed grid, therefore, will require a higher negative potential on the grid than a close-meshed grid to reduce the sheath current to zero.

259. The effect on the sheath-current curve of opening the mesh is therefore very much the same as that of increasing the sheath potential, that is to say, it shifts the valve-current curve bodily to the left. It also tends to reduce the steepness of the curve.

260. The effect on the sheath-current curve of reducing the distance between the filament and the grid is very much the same as opening the mesh of the grid, inasmuch as it necessitates a higher negative E.M.F. on the grid to reduce the sheath current to zero. The reason for this is easy to see if we take an extreme case and suppose that the grid is brought so close to the filament that it almost touches it.

261. Under such conditions the electrostatic lines of force produced by a given charge on the grid between it and the filament would be concentrated close to the grid wire, thus leaving the space between the grid wires free of any field which would otherwise neutralise the

field induced by the charge on the sheath. Thus a greater number of lines of force emanating from the sheath can reach the filament for a given grid potential,

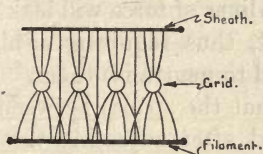


FIG. 58a.

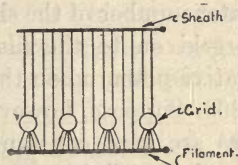


FIG. 58b.

and consequently a higher negative grid potential is required to neutralise this field.

To make this point quite clear, we have illustrated in Figs. 58a and 58b the relative distributions of the field induced between the sheath, the grid, and the filament when the grid is alternatively some distance away from or very close to the filament.

262. To avoid confusion let us sum up these effects by taking an example. Imagine a valve

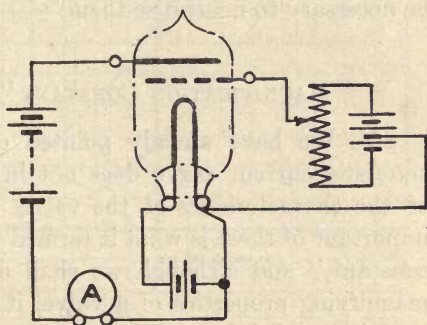


FIG. 59.

connected up, as shown in Fig. 59, with a certain fixed high-tension battery connected in the sheath circuit, and suppose the potentiometer in the grid circuit is adjusted to exactly that value which will just stop all flow of current through the valve, that is, when the field produced by the grid exactly neutralises all the field which leaks past it from

the sheath to the filament. Now imagine that the wires forming the grid are reduced in number, leaving larger spaces between them. The effect of this will be that a greater number of the sheath lines of force will leak past the grid on to the filament, thus requiring a higher negative potential on the grid to neutralise them.

263. Suppose, however, that the spaces between the wires are kept constant, and after adjusting the grid potential, as before, so that the field which leaks past the grid from the sheath is just neutralised by the field produced by the grid, the latter is brought nearer to the filament. The effect of this will be that the grid field will be concentrated locally, and will not, therefore, entirely neutralise the sheath lines of force which leak past it, consequently a higher grid potential will again be necessary to neutralise them.

#### “MAGNIFICATION CONSTANT” OF VALVES

264. We have already pointed out that the characteristic current curve does not in itself illustrate all of the characteristics of the valve. One of the most important of these is what is termed the “magnification constant,” and although we shall deal later with the magnifying properties of a valve, it may be as well to explain here briefly what is meant by the term “magnification constant.”

265. **The magnification constant of a valve is the ratio between a change in the E.M.F. of the sheath to the corresponding change in the E.M.F. of the grid which is necessary to maintain the sheath current at any pre-determined value.**

266. Exactly what this means can easily be seen if

we examine the characteristic curves of a valve obtained with different sheath potentials. Such curves were illustrated in Fig. 51, which, as we explained in paragraphs 228 to 232, show the effect of applying a higher or lower potential to the sheath. If these curves be examined carefully it will be seen that for every additional 50

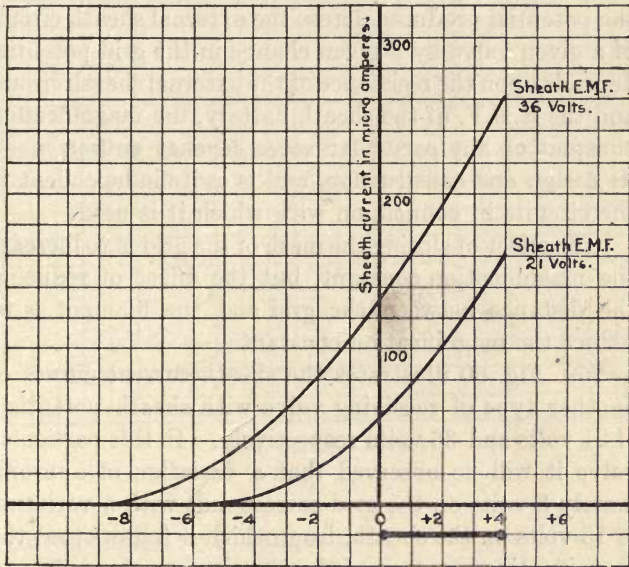


FIG. 60.

volts applied to the sheath, the curve is moved back about one volt along the horizontal axis.

267. For example, it will be seen that the grid potential necessary to allow a current of 200 micro-amperes to flow through the valve is 0 when the sheath potential is 50 volts, -1 volt when the sheath potential is 100 volts, and -2 volts when the sheath potential is



150 volts. We may say, therefore, that maintaining a constant current of 200 micro-amperes through this particular valve, a change of 50 volts on the sheath corresponds to a change of 1 volt on the grid. From this it will be seen that the magnification constant of the valve is 50.

268. Although, as we shall show later, the change in the potential produced across the external sheath circuit of a given valve by a given change in the grid potential depends upon the resistance of the external sheath circuit and the E.M.F. of the sheath battery, **the magnification constant of any particular valve depends entirely upon its design and construction**, and is quite independent of the circuits in connection with which it is used.

The effect of closing the mesh of the grid is to increase the magnification constant, but the effect of reducing the distance between the grid and the filament is to reduce the magnification constant.

269. Fig. 60 illustrates the sheath-current curves of another type of receiving valve with sheath potentials of 21 volts and 36 volts respectively. In this particular valve it will be observed that a variation of approximately 3 volts on the grid corresponds with a variation of 15 volts on the sheath, from which it follows that the magnification constant of that particular valve is 5.

Fig. 61 illustrates the sheath-current curves of a small transmitting valve suitable for a power of about 50 watts, with sheath potentials of 1000 volts and 1500 volts respectively. The magnification constant of this particular valve is 120. It will be noticed that in this case the ordinates are calibrated in milliamperes instead of micro-amperes. The scale to which the curves are drawn makes no difference, as what we

require to know is the change in the grid potential

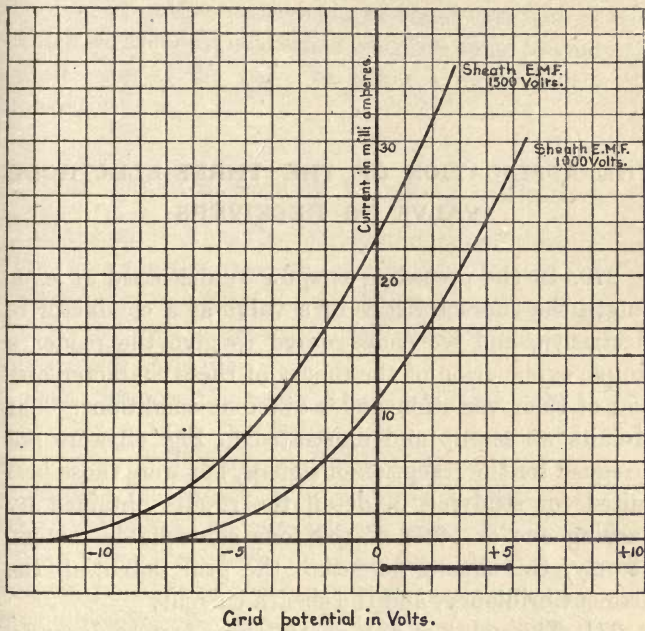


FIG. 61.

corresponding to a change in the sheath potential for a constant current. It is not necessary to know the actual value of that current.

## THE APPLICATION OF THE THREE-ELECTRODE VALVE TO RECEIVERS

270. IN the preceding chapter we discussed at some length the characteristics of a valve as a conductor of electricity, and we endeavoured to give the reader a simple explanation of the theory of these characteristics and of their variation under different conditions. The circuits we set up and illustrated in Fig. 48 were not designed for the reception of signals, but were those best suited for studying in detail the results obtained by varying one or other of the four controllable factors, namely, the sheath potential, the grid potential, the filament brilliancy, and the sheath current.

271. The value of any one of these factors depends, as we have seen, upon the values of the other three; thus the value of the sheath current depends upon (1) the sheath potential, (2) the grid potential, and (3) the filament brilliancy. But in a curve diagram it is only possible to illustrate the relationship of two factors whose values are dependent upon one another. In order, therefore, to illustrate graphically the results obtained, it was necessary to keep two of the four factors constant and to show the relationship between the other two, plotting a separate curve for each change made in either of the constant factors.

In every case the curves illustrated show the relationship between the grid potential and the sheath current, because it is the relationship of these two factors with which we are most concerned when we come to study the application of the valve to either a receiver or transmitter.

### THE THREE-ELECTRODE VALVE AS A RECTIFIER

If the student has thoroughly understood the explanations given in the preceding paragraphs, he will have no difficulty in following the method commonly employed for rectifying the received oscillations by means of a three-electrode valve.

272. Suppose the valve is connected up, as shown in Fig. 52, so that the battery maintains the filament at normal brilliancy, and the high-tension battery maintains the sheath at a uniform positive potential relatively to the filament, and the grid is left insulated.

For reasons explained in paragraph 236 the grid will become quickly charged to a certain negative value, and thus automatically stop all flow of current through the sheath circuit. The value of this negative potential for any particular valve depends, as we have seen, upon the E.M.F. of the high-tension battery. Let us take a concrete example and assume that the characteristic curves of the valves used in the following explanations are as illustrated in Fig. 62. Assuming, therefore, that the E.M.F. of this battery is 100 volts, it is clear that the insulated grid will become charged to a potential of  $-1.5$  volts.

273. If now we connect the grid to the circuits of a receiver in such a way that the oscillations induced in the latter by the incoming signal cause a variation of the

potential of the grid relatively to the filament, it is evident that during the positive half of each oscillation a current will flow in the sheath circuit of the valve, but during the negative half of each oscillation no current

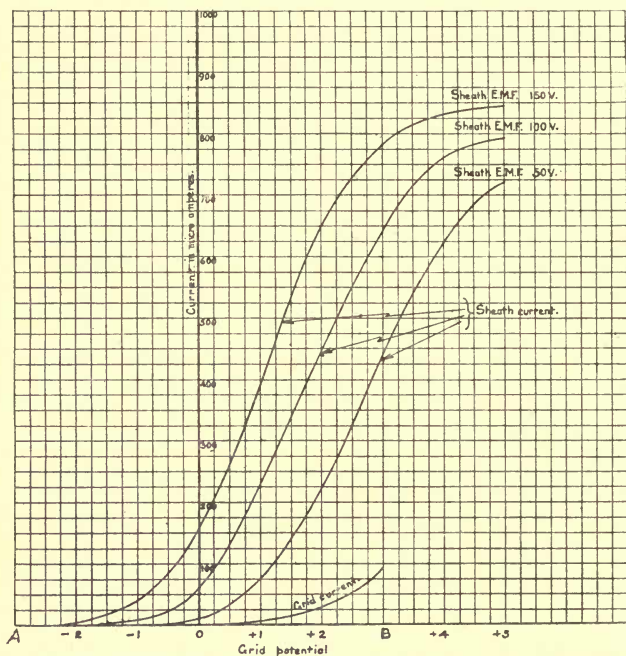


FIG. 62.

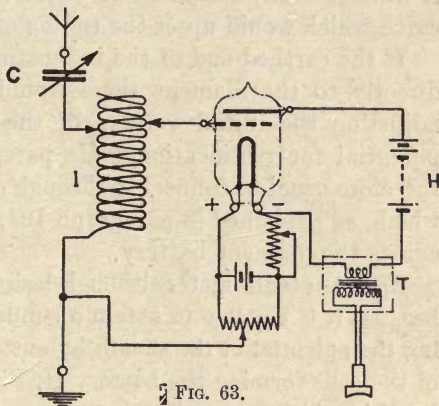
will flow. Thus, although there is no rectification of the high-frequency current flowing in the receiver circuits, the effect is to cause a number of high-frequency unidirectional pulses to flow in the sheath circuit which amount to a rectified current.

274. Bearing in mind the explanation given in para-



graphs 11 to 29 of the action of a rectifier, it is easy to see that a pair of telephones connected in the sheath circuit of the valve will respond to the current thus produced. It is also evident from the explanations given in paragraphs 170 to 186 that the efficiency of the valve as a rectifier, *i.e.* its sensitiveness, can be improved by adjusting the initial potential of the grid to some value around the bend in the characteristic curve. In the valve under consideration this value will be somewhere between  $-1$  and zero volts.

In Fig. 63 we have shown diagrammatically the connections of a three-electrode valve used as a rectifier in conjunction



with a receiver following these principles. The receiver illustrated is a single circuit receiver consisting of a variable inductance  $I$  and condenser  $C$  connected in series with the aerial, and tuned to the incoming signal.

275. The oscillations induced in the aerial create an oscillatory E.M.F. across the inductance  $I$  and also across the condenser  $C$ . But provided the inductance of  $I$  forms a large proportion of the total inductance of the aerial circuit, that is, provided the received wave-length is considerably longer than the fundamental wave-length of the aerial, the maximum difference in potential

between any two points on the accessible portion of the aerial circuit will be across the inductance I.

276. The grid circuit of the valve is therefore connected across this inductance. It should be noted, however, that in this form of receiver it is **necessary to connect the grid to the aerial end of the inductance**, and the filament to the earthed end, because the filament battery might otherwise form a leak to earth, or even if it were carefully insulated it would form a capacity to earth which would upset the tuning of the receiver.

If the earthed end of the inductance were connected directly to the filament there would be no means of adjusting the initial voltage of the grid to the best potential for rectification (*vide* paragraph 274); it is therefore usual to connect it through a potentiometer P, which, as explained in paragraph 194, can be connected across the filament battery.

277. A potentiometer although desirable is not essential, because it is **possible to obtain a similar effect by adjusting the potential of the sheath** by cutting in or out some of the cells forming the battery H, Fig. 63. The reason for this will become clear if we examine the characteristic curves illustrated in Fig. 51 and again in Fig. 62 showing the effect of varying the potential of the sheath. As pointed out at the time, the effect of raising the potential of the sheath is to shift the curve bodily to the left, so that if the initial potential of the grid is definitely fixed at some predetermined value (which value would be zero if connected directly to the negative end of the filament), it is possible to make this potential correspond with any desired point on the valve curve by raising or lowering the potential of the sheath. Although there are practical

limits to the extent to which this adjustment can be made, owing to the fact that the sensitiveness of the valve is reduced by a lower sheath potential, it is nevertheless frequently preferred to sacrifice a certain amount of efficiency in order to simplify the receiver by cutting out the potentiometer.

278. In the diagram illustrated in Fig. 63 it will be noticed that the telephones, instead of being connected directly in the sheath circuit, are connected to a transformer T, the primary of which is connected in the sheath circuit. The reason for this is that the voltage of the battery H may be as much as 150

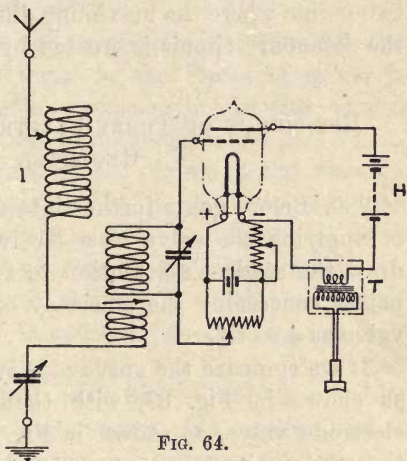


FIG. 64.

volts according to the design of valve, and if the telephones were directly connected to this there would be some chance of the operator receiving a nasty shock through inadvertently touching exposed wires, in addition to which the insulation between the telephone windings and the container would be strained if not burnt out. Provided the insulation of the transformer is good, there is no such chance with the telephones connected as shown, because the voltage across the secondary of the transformer is only proportional to the **variation** in the voltage across

the primary, and is therefore absolutely independent of the voltage of the battery H.

279. The three-electrode valve can also be used in this way in connection with a two-circuit receiver, as shown diagrammatically in Fig. 64. Such a receiver, although more complicated and expensive, has the advantage of being more sensitive to short wave-lengths. The reason is that the valve can be connected to the two points where the maximum difference in potential in the secondary circuit is created by the incoming signal.

#### EFFICIENCY OF THREE-ELECTRODE VALVE AS A RECTIFIER

280. Before going further into the different methods of applying the valve to a receiver, it is desirable to draw the student's attention to one or two important points concerning the efficiency of the three-electrode valve as a rectifier.

If we compare the curve of a typical Fleming Valve, as shown in Fig. 37, with that of a typical three-electrode valve, as shown in Fig. 62, it will be found that the rectified current caused by E.M.F. oscillations of given amplitude is practically the same in both cases.

281. For example, an oscillation having an amplitude of 2 volts applied to the particular Fleming Valve in question, the initial potential of which is adjusted to, say, +.5 volt, will cause an increase of 73 micro-amperes during the positive half and a decrease of 21 micro-amperes during the negative half of each oscillation. The effective current through the telephones will, therefore, be 62 micro-amperes.

282. The same oscillation applied to the three-



electrode valve, whose curve is illustrated in Fig. 62, the initial potential of which is adjusted to  $-1$  volt, will cause an increase of 55 micro-amperes during the positive half and a decrease of 8 micro-amperes during the negative half of each oscillation. The effective current through the telephones will, therefore, be 47 micro-amperes. In this case it would appear at first sight that the Fleming Valve is distinctly more sensitive than the three-electrode valve.

This, however, is not necessarily so, because the energy given to the aerial by the incoming signal is limited, and therefore any expenditure of this energy will reduce the amplitude of the oscillations.

283. Now if we examine the circuit of the Fleming Valve receiver illustrated in Fig. 40, it will be seen that **the rectified current which operates the telephones flows through the inductive winding of the oscillatory circuit**, and at all events some of the energy which is expended in the telephones is actually drawn from the energy supplied by the incoming signal, which, as just pointed out, is limited. **In other words, the Fleming Valve circuit acts as a leak to the aerial during the positive half of each current oscillation in the aerial circuit.** The result is that the amplitude of the current oscillations, and therefore also that of the E.M.F. for a given strength of signal, is reduced, thereby reducing the efficiency of the valve as a rectifier, and moreover **the damping of the circuit is increased, thereby reducing the sharpness of tuning.**

284. This reduction in the sharpness of tuning is, on account of the higher efficiency of the valve for greater amplitudes, obviously more pronounced in the case of strong signals than in the case of weak signals. It therefore becomes a matter of considerable importance



in practice, as jamming is always more troublesome when the interfering signal is stronger than the one it is desired to receive.

285. If we examine the circuit of the three-electrode valve receiver illustrated in Fig. 63, it will be seen that the **rectified current which operates the telephones is supplied from a source entirely independent to the energy generated in the aerial**, and that none of the aerial current can possibly pass through the sheath circuit of the valve, because no electrons are generated at the grid.

286. The only possible path for the current to leak out of the aerial circuit is through the grid circuit, *i.e.* from the grid to the filament. Obviously, this can only occur when the grid is positive to the filament. Thus, referring again to the curve illustrated in Fig. 61, it is evident that **so long as that part of the curve on which the E.M.F. variation of the grid works is to the left of the zero potential line, no current can flow from the grid to the filament, and therefore no energy can be transferred from the aerial to the valve.** The result is that under these conditions the amplitude of the E.M.F. oscillations set up in the receiver circuits by a given strength of signal is greater than in the case of the Fleming Valve receiver, and the damping of these oscillations is very much less.

287. If, however, that part of the curve on which the E.M.F. variation of the grid works lies to the right of the zero potential line, then a certain amount of current can leak from the aerial through the grid circuit, thus damping the aerial oscillations. But since the value of this current is very small compared with that which is lost in the Fleming Valve receiver, as will be seen by comparing the **grid current curve** in Fig. 62 with the

Fleming Valve curve in Fig. 37, it follows that in any case the damping of a three-electrode valve receiver will be less than that of the Fleming Valve receiver.

288. It is important to note, however, that for the sake of avoiding any loss the design of the valve used and the E.M.F. of the sheath should be such that the rectification point is well to the left of the zero grid potential line.

### THE GRID CONDENSER METHOD OF RECTIFYING

289. There is another method of using the three-electrode valve for the purpose of rectifying or rather of producing unidirectional current pulses in the telephone circuit, which, to distinguish it from the ordinary method just described, we may term the "grid condenser method."

290. In paragraphs 177 and 178 we explained how the efficiency of the Fleming Valve as a rectifier was very much reduced for weak oscillations by reason of the fact that it is necessary, in order to obtain rectification, to adjust the initial potential of the valve to some point **on the bend of the curve**, and that, owing to the bluntness of the bend, small E.M.F. variations only work on a comparatively flat part of the curve.

It is evident that if we could so arrange matters that we obtain rectification when the initial potential is adjusted to the steepest part of the curve, the sensitiveness of the receiver would be greatly enhanced.

291. The necessary conditions for obtaining rectification on this part of the curve can be obtained with a three-electrode valve by connecting a small condenser in series with the grid. The explanation is simple

enough if we take one thing at a time and make quite sure that we understand that thoroughly before going further.

292. Let us, therefore, set up a simple electrical circuit, as shown in Fig. 65, consisting of two condensers A and B connected in series, across some source of variable E.M.F. such as a potentiometer. If the potentiometer be connected as shown in the diagram, it is clear that by moving the slider to the right (*i.e.* to X) the

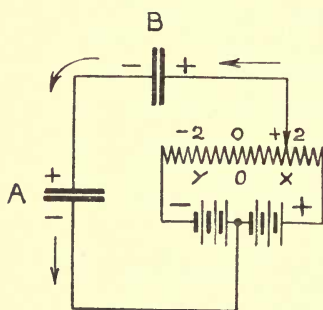


FIG. 65.

condensers will be charged in one direction, and by moving the slider to the left (*i.e.* to Y) the condensers will be charged in the reverse direction, while if the slider occupies the middle position O there will be no potential whatever across the circuit.

293. If then the slider be moved from O to X there will be a momentary displacement of electricity in the circuit in the direction shown by the arrows in the diagram, and both condensers will become charged in the direction indicated by the + and - signs near them. The displacement of electricity is only momentary, because, as soon as sufficient current has passed into the condensers to charge them up, they exert an equal and opposite potential to the applied E.M.F. Assuming, for the sake of simplicity, that both condensers have exactly the same capacity, they will both become charged to exactly half the E.M.F. across the circuit. Thus if

the E.M.F. from O to X is 2 volts the E.M.F. across each condenser will be 1 volt.

294. If we move the slider back to O there will be another momentary displacement of electricity in the circuit, and both condensers will come to zero potential ; and similarly if the slider be moved to Y each condenser will become equally charged in the reverse direction.

295. It is evident that in this circuit any variation of the E.M.F. applied to it will cause a corresponding change in the E.M.F. across each condenser, so that if the potentiometer be replaced by some source of alternating E.M.F., the E.M.F. across each condenser will also alternate on either side of zero potential at the same frequency.

296. Now let us see the effect of connecting a **unidirectional conductor** across one of the condensers. For example, suppose we connect an ordinary Fleming Valve across the condenser A as shown in Fig. 66, where for the sake of simplicity we have eliminated the filament battery. For the same reason let us assume that the valve is a perfect conductor to a current passing from the sheath to the filament and a perfect insulator to any current tending to pass from the filament to the sheath.

297. If with such an arrangement we start by moving the slider from O to X it is evident that there will again be a momentary displacement of electricity in the direction indicated by the arrows, and the condenser B, as before, will become charged in the direction indicated by the positive and negative signs in Fig. 66. **The condenser A, however, will receive no charge, because to a current flowing in this direction the valve offers no resistance, and the condenser, therefore, acts as though**

it were short circuited. It is also evident that since the condenser A acts as though it were short circuited, the

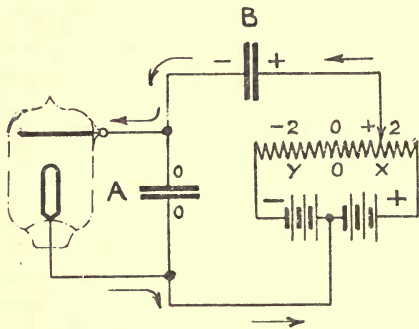


FIG. 66.

condenser B will now be charged to the full value of the positive E. M. F. applied by the potentiometer, instead of to only half the value as in the previous experiment, and therefore there will be

double the displacement of electricity through the circuit.

298. If we now move the slider back to the position

O there will once more be a displacement of electricity in the circuit in the direction indicated by the arrows in Fig. 67, but this time the current which was displaced through the

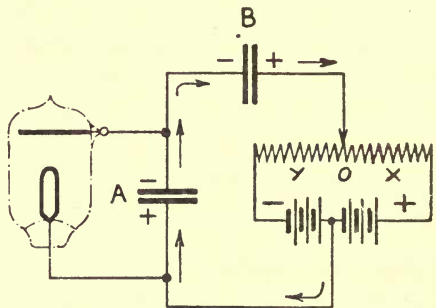


FIG. 67.

valve is not able to return by the same path, because no current can pass from the filament to the sheath. The result is that the electricity originally displaced passes into the condenser A, charging it up in



the opposite direction as indicated by the + and - signs near A in Fig. 67. Owing to the back E.M.F. now exerted by the condenser A, however, it is clear that only part of the original quantity of electricity displaced through the valve will flow into the condenser A, with the result that the condenser B can only become partly discharged, and therefore still retains some of its original charge as indicated by the + and - signs near B in Fig. 67.

299. If the electrical condition of the circuit is now examined it will be observed that although zero potential is exerted by the potentiometer, and therefore the circuit is in a state of static equilibrium, yet the dielectrics of both condensers are in a state of strain, the condenser A exerting an E.M.F. in the opposite direction to that exerted by the condenser B, with the result that that part of the circuit to which the sheath of the valve is connected is negative to that part of the circuit to which the filament is connected.

300. The particular point which we wish the reader to understand is that the effect of the small current passing through the valve in the first instance, *i.e.* when the potentiometer is first moved from O to X, is to alter permanently the potential of the sheath of the valve negatively by a certain value depending upon the value of the maximum positive E.M.F. applied to the circuit. So long as no greater positive E.M.F. is applied to the circuit, that is to say, so long as the slider is not moved further to the right than the point X, no further current can pass through the valve, because the potential of that side of the condenser A, to which the sheath is connected, can never be at a positive potential to that side to which the filament is connected.

301. It will be seen also that after this first permanent displacement of the potential balance in the circuit, any further variation of the E.M.F. applied to the circuit will cause a corresponding change in the E.M.F. of both condensers, so long as the applied E.M.F. does not exceed the maximum positive E.M.F. applied in the first instance.

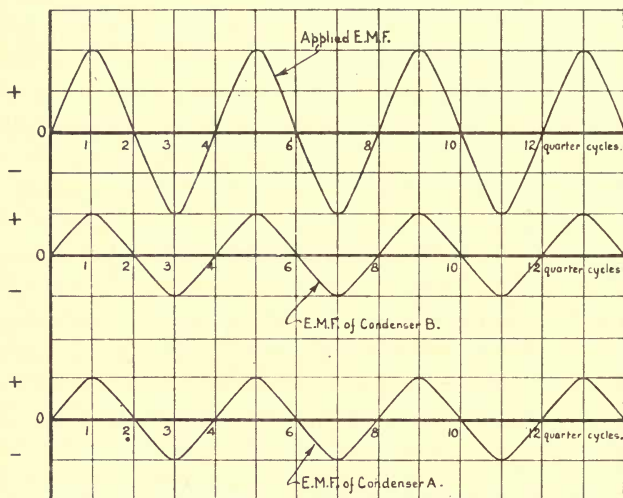


FIG. 68.

302. If in the experiments just described the potentiometer be replaced by some source of alternating E.M.F. it is evident that **during the first quarter cycle** (assuming that it is positive) the condenser B will become charged to the maximum peak value of the alternation, but the condenser A will remain at zero potential on account of the short-circuiting action of the valve; **during the second quarter cycle**, however, the charge in the con-

denser B will be reduced by one-half while the condenser A will start charging in the opposite direction ; **during the third quarter cycle** the condenser B will continue to lose its original charge and, assuming that the capacities of the two condensers are equal, will reach zero potential at the end of the third quarter cycle while the charge in the condenser A will increase ; **during the fourth**

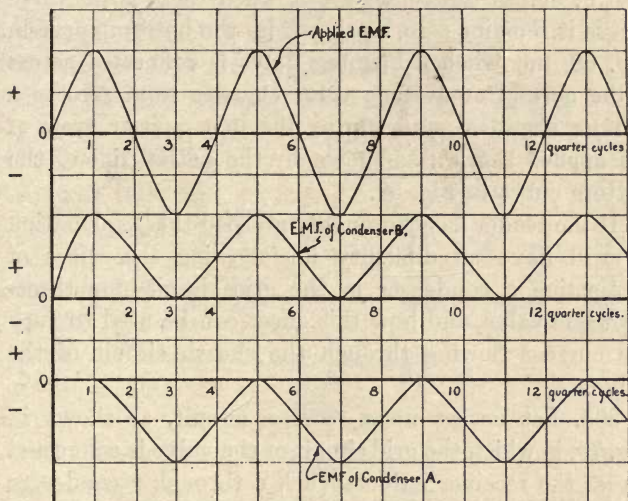


FIG. 69.

**quarter cycle** the condenser B will again start charging, while the condenser A starts discharging, and so on.

303. To make the point quite clear and to show the effect of the action of the valve, we have illustrated by curve diagrams in Figs. 68 and 69 the effect of applying an alternating E.M.F. across a circuit consisting of two condensers in series. Fig. 68 illustrates the conditions described in paragraph 295 when both condensers are

perfectly insulated, while Fig. 69 illustrates the conditions described in paragraph 302 when the condenser A is shunted by a Fleming Valve. In Fig. 69 the dotted line shows the average value of the E.M.F. across the condenser A.

304. The point of difference to be observed between the two cases is that the normal or average value of the E.M.F. across the condenser A when there is no valve across it remains zero, as shown by the bottom curve in Fig. 68, but **when a Fleming Valve is connected across it the normal or average value changes from zero to a definite negative value during the first quarter cycle of the applied E.M.F.**, as shown by the dotted line of the bottom curve in Fig. 69.

If the reader has thoroughly grasped this explanation he will have no difficulty in following the effect of connecting a condenser in the grid circuit of a three-electrode valve, and how this effect can be used to vary the current flowing through the sheath circuit of the valve.

305. Let us set up a receiver circuit, as shown in Fig. 70, in which the grid circuit of the valve is connected across the receiver inductance XY through a condenser B. To emphasise the similarity between the grid circuit of this receiver and the circuits illustrated in Figs. 66 and 67, we have dotted in another condenser A across the grid and filament of the valve. This condenser, however, is unnecessary in practice, because **the grid and filament themselves actually form the two plates of a small condenser.**

306. The source of variable E.M.F. in the circuit we are now considering is the inductance XY in which high-frequency alternations are set up by the incoming

signals, and this therefore corresponds with the potentiometer in Figs. 66 and 67. The grid and filament of the three-electrode valve act as the sheath and filament of a Fleming Valve, inasmuch as a current can pass from the grid to the filament when the potential of the former is positive, as indicated by the grid current curve illustrated in Figs. 62 and 71 and explained in paragraph 248. It is easy to see, therefore, that the grid circuit of the diagram illustrated in Fig. 70 is essentially the same as the circuit illustrated in Fig. 66.

307. Let us suppose that the grid and sheath current curves of the valve used in this arrangement are those shown in Fig. 71. This being so, and assuming that before any signal is received

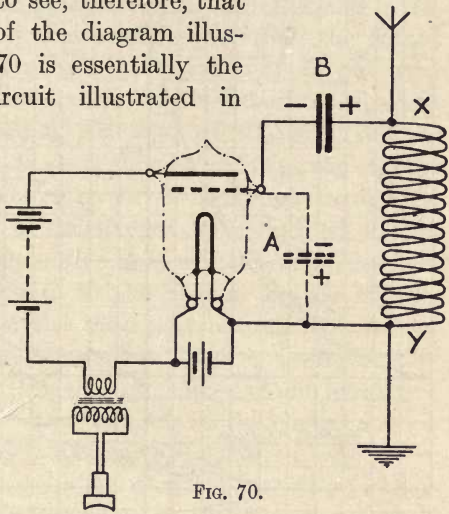


FIG. 70.

the E.M.F. across the condenser B (Fig. 70) is zero, it is obvious that the grid is at zero potential to the filament, and that under these conditions a steady current of 300 micro-amperes will flow through the sheath circuit.

308. If now the incoming signal creates an oscillatory E.M.F. across XY having an amplitude of, say, 1 volt, and assuming that the capacity of A is equal to that of B, it is clear from the explanation given in paragraph



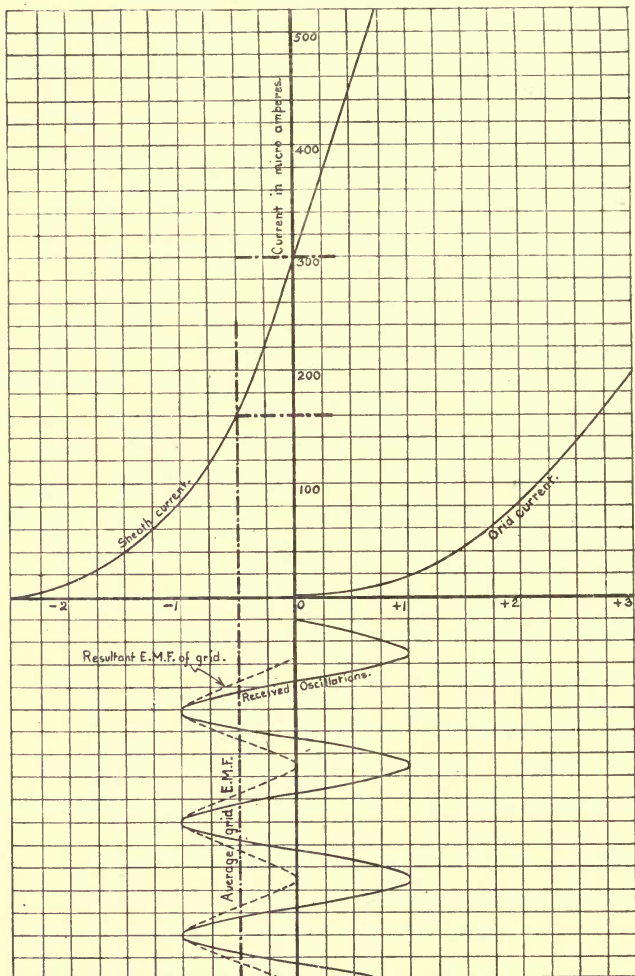


FIG. 71.

301 that the normal potential of the grid, owing to the leakage of current from the grid to the filament during the first quarter cycle, will raise the normal potential of the grid to a negative value of  $-.5$  volt, and that this potential will thereafter alternate at radio frequency between  $-1$  volt and zero volts.

309. Thus the full line E.M.F. curve in Fig. 71 shows the variation of the potential at the point X and corresponds with the top curve in Fig. 69, while the dotted line curve (Fig. 71) shows the variation of the potential of the grid and corresponds with the bottom curve in Fig. 69. The normal potential of the grid is thus changed from zero to  $-.5$ , thereby reducing the current through the sheath circuit from 300 to 160 micro-amperes.

310. If a pair of telephones be connected in the sheath circuit of the valve it is evident that they will respond in proportion to the change in the current affected, that is, to the difference between 300 micro-amperes and 160 micro-amperes. The subsequent alternations of the E.M.F. of the grid, being at radio frequency and acting on the straight part of the curve, do not affect the current through the telephones.

311. There is an obvious limitation to the method described above and illustrated in Fig. 70, namely, that after the first E.M.F. impulse has acted on the circuit the latter can no longer respond to signals of the same amplitude (*vide* paragraph 300). This, however, is not quite the case in practice, because the current which flows from the grid to the filament for a given positive E.M.F. applied to the former is limited and is insufficient to allow the full change in the potential of the grid to take place in one step. The result is that the grid potential, instead of being raised to a value of  $-.5$  volt

during the first quarter cycle, requires a considerable number of positive impulses to effect this change. However, whether the change be effected in a greater or less number of cycles, it is obvious that sooner or later the maximum permanent change in the potential of the grid for a given amplitude of signal must be reached, and the receiver would then no longer respond

to signals of similar or lower amplitude.

312. This difficulty could be overcome by periodically discharging the condenser B, thus giving the circuit a fresh start every now and again, but this would cause a loud click in the

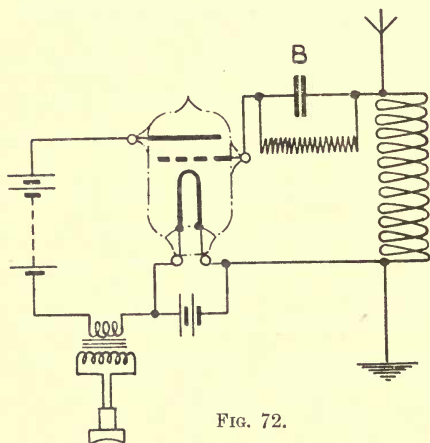


FIG. 72.

telephones due to the consequent increase in the current every time the condenser was discharged. A better way of accomplishing practically the same thing is to **connect a high-resistance leak across the grid condenser** as shown in Fig. 72. The value of the resistance of this leak must be low enough to allow the condenser to discharge more or less completely during the time interval between the successive trains of waves constituting a spark signal, and at the same time high enough not to reduce seriously the degree to which the condenser is charged by a given group of E.M.F.

oscillations. The best value for the leak resistance is evidently different for different strengths of signals, but as it is difficult and inconvenient to arrange an adjustment of its value it is usually fixed for average signals, although at the expense of efficiency.

313. In the explanation of the theory of the action of this arrangement we supposed for the sake of simplicity that the capacity of the grid condenser was equal to that of the valve (*i.e.* the capacity between the filament and the grid). This condition, however, is not necessary, and as a rule the capacity of the grid condenser, although extremely small, is very much larger than that of the valve. The grid condenser usually has a capacity of somewhere about  $\cdot 0001$  microfarad, and the resistance of the leak is usually somewhere about 1 megohm.

314. Yet another way of discharging the grid condenser is to connect across it a crystal, having unidirectional properties, such as carborundum. This has the advantage of offering a very high resistance to a current tending to pass through it in one direction, which can be so arranged as to prevent as far as possible any serious reduction in the degree to which the condenser is charged by a group of received oscillations, and at the same time to offer a comparatively low resistance in the other direction, thus allowing the condenser to discharge quickly (*vide* paragraph 312).

315. The object of the grid condenser method of rectification is to increase the sensitiveness of the detector to weak signals by working on the steep part of the valve-current curve. Under favourable conditions the method is undoubtedly more sensitive, but the apparent advantage is considerably modified by the

effect of the leak, and, moreover, strong signals from an interfering station or a strong atmospheric is liable to cause a complete "wipe out" for an appreciable length of time until the extra high charge thereby given to the condenser has had time to discharge through the leak.



## THE VALVE AS A MAGNIFIER

### MAGNIFYING PROPERTIES OF THE VALVE

316. IN paragraphs 264 to 269 we explained what was meant by the magnification constant of a valve. We have not, however, made it clear in what respect the valve can be regarded as a magnifier of energy or to what extent it can magnify.

As a matter of fact it is not possible to magnify energy any more than it is possible to magnify the weight of a cubic inch of iron. It is true we can make

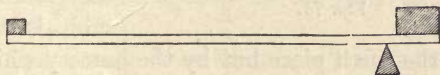


FIG. 73.

a cubic inch of iron lift, say, 12 cubic inches of iron by placing the former on the long arm and the latter on the short arm of a lever, as illustrated in Fig. 73. But even if the lever be termed a magnifier of weight, it cannot be regarded as a magnifier of energy, because the energy expended by a falling body is the product of its mass and the distance it travels, and is measured in "foot pounds." It will be seen that the small piece of iron at one end of the lever must drop 12 inches to

lift the large piece of iron 1 inch at the other end of the lever.

317. Suppose, however, we mount an electromagnet above the large piece of iron, as shown in Fig. 74, and connect this magnet to a battery through a small switch S which can be closed by the weight of the small piece of iron. It is easy to see that, provided the battery is big enough and the electromagnet powerful enough, a very small movement of the small piece of iron will close the switch S and cause the electromagnet to lift the large piece of iron a similar or even greater distance.

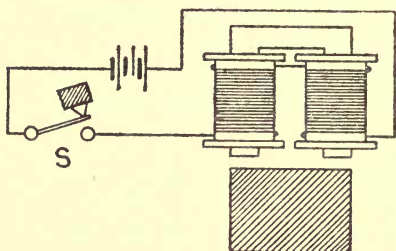


FIG. 74.

Such an apparatus might conceivably be termed an energy magnifier, but in reality it is only a relay, because the energy expended in lifting the large piece of iron is not supplied

by the small piece but by the battery which works the electromagnet.

318. In the same way the three-electrode valve, although frequently termed a magnifier, is in reality merely an electrical relay, because the energy which is liberated in the sheath circuit and which is used to operate the telephones is not supplied by the circuit which acts on the grid, but is merely controlled by it.

319. It would seem at first sight that the so-called magnifying properties of a single relay are infinite. For instance, in the electro-mechanical example of a relay we have just taken it might be argued that, provided we

supply a big enough battery and a powerful enough magnet, an extremely small expenditure of energy on the switch can cause the magnet to lift an unlimited weight. Theoretically this may be so, but in practice the relay has very well-defined limitations. For example, if in the illustration we have taken we increased the size of the battery and magnet, we should require a proportionately heavier switch to close the circuit without fusing the contacts, and this heavier switch would require considerably more power to operate it. If this extra power is not available, then it is evident that the arrangement can only be used to a limited extent.

320. It is, however, quite a simple matter to increase the effect to any desired extent if we use more than one relay. For example, we can construct the first relay so that the energy liberated in the electrical circuit operates the switch of another and larger relay, and this can be repeated as many times as may be necessary. In the same way a series of valves can be used to magnify the current variations induced by the received signals to any desired extent.

321. What then are the limitations of the valve as a relay or magnifier? We know that to get the maximum variation of the sheath current we must apply a varying E.M.F. to the grid having the greatest possible amplitude. The power available for this purpose is limited by the strength of signal, but since power is the product of the E.M.F. and the current we can by means of transformers increase the amplitude of the E.M.F. oscillations at the expense of the current. This, however, in practice can only be done to a limited extent, for two reasons.

322. In the first place, we must have sufficient current to charge the grid; for although under suitable

conditions, as we have seen, no current will flow through the grid circuit, yet the grid itself has, as we have already noted, a certain capacity, and according to the value of this capacity a certain quantity of electricity must flow into it to charge it up to a given potential. The value of this capacity is so extremely small, however, that the value of the necessary current is practically negligible.

323. The second and by far the more important

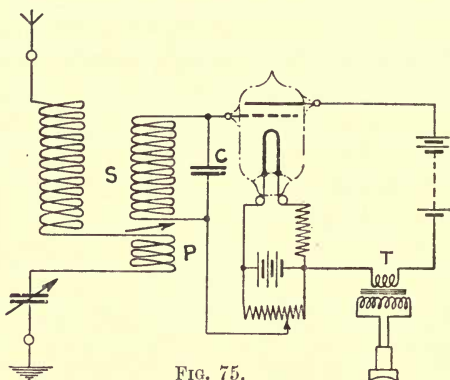


FIG. 75.

consideration is **the capacity of the transformer windings**. If we take the case of a two-circuit receiver using a single valve, as illustrated in Fig. 75, the transformer in question is the "Jigger," consisting of a primary winding P connected in the aerial circuit and a secondary winding S connected across the grid circuit. **It is the capacity of this secondary circuit which limits the extent to which we can increase the amplitude of the E.M.F. at the expense of the current.** The circuit, of course, must be in resonance with the incoming wave, and, for the purpose of tuning, a condenser C is connected across the

secondary winding. Increasing the inductance of the winding S enables us to reduce the capacity of the condenser C for a given wave-length, and we can thus increase the amplitude of the E.M.F. oscillations for a given strength of signal; but quite apart from the capacity of the condenser C, the winding itself has a capacity of its own, which increases with the number of turns forming the coil, so that a limit is reached when the capacity of C is reduced to zero and the inductance and self-capacity of S are such that the wave-length of the jigger secondary by itself is the same as that of the received signal.

It is quite evident, therefore, that no further reduction of the capacity of this circuit is possible, and therefore **for a given strength of signal we can only produce a limited variation of the grid potential, and therefore also of the current flowing in the sheath circuit.** Let us then turn our attention to the sheath circuit, and see what can be accomplished in that direction.

324. According to the design of the valve and the conditions under which it is used, a given change in the grid potential will cause a definite change in the sheath current, and we have from time to time illustrated by curves the relation between these two factors **when there is no resistance in the external circuit.** It does not follow, however, that the current indicated by these curves for a given grid potential will flow through any external circuit. For instance, suppose that the resistance of the external sheath circuit is infinitely great, which could be brought about by interrupting the circuit. Then it is evident that, no matter what the value of the grid potential, no current can flow through the valve.

325. We have also seen that, according to the design



of the valve, a given change in the grid potential will cause a definite change in the potential across the sheath circuit. It does not follow, however, that the full change in the sheath potential for a given change in the grid potential will be produced in any external circuit. For instance, suppose the resistance of the external sheath circuit be zero, which could be brought about, for example, by short circuiting the telephone transformer windings in Fig. 75, then it is evident that, no matter what the change in the grid potential, no change will be effected in the potential across the sheath circuit. The magnification constant indicates the resulting change in the sheath potential **when the resistance of the external sheath circuit and the E.M.F. of the sheath battery are both infinitely high.**

326. These points are easier to understand if we regard the valve as a conductor of variable resistance connected in the sheath circuit. Its resistance  $R$  can be calculated by Ohm's Law,  $R = \frac{E}{C}$ , where  $E$  is the

voltage of the sheath battery and  $C$  the current flowing through the sheath circuit. Since the current flowing through the sheath circuit for a given sheath potential varies with the grid potential, it follows that also **the resistance of the valve for a given sheath potential varies with the grid potential.** For example, taking the valve whose curves we have illustrated in Fig. 62, it will be seen that with a sheath E.M.F. of 150 volts the resistance of the valve is about  $10^6$  ohms when the grid potential is 0 and about 260,000 ohms when the grid potential is 1 volt.

It is clear that we can represent the sheath circuit of a valve by a simple electrical circuit, such as that illus-

trated in Fig. 76, where  $r$  represents the valve, H represents the sheath battery, and R represents the external circuit. In the case of the valve circuit proper a variation of the potential of the grid causes a change in the resistance of the valve, while in the analogous circuit illustrated in Fig. 76 a change in the position of the slider P causes a change in the resistance of  $r$ .

327. It is easy to show that for a given change in the resistance of  $r$  (say from A to B) the biggest change in the current will occur when the resistance of R is zero, but that for a given change in the resistance of  $r$  the biggest change in the potential across R will occur when its resistance is exactly equal to that of  $r$ .

To show this let us take a practical example, and, assuming different values for R, work out from Ohm's Law the change in the E.M.F. across R and of the

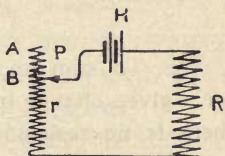


FIG. 76.

current flowing through the circuits for a given change in the resistance of  $r$ .

If C is the current flowing through the circuit, R and  $r$  the resistance of R and  $r$  respectively, and E the E.M.F.

of the battery H, then from Ohm's Law  $C = \frac{E}{R + r}$ .

Also, if V is the potential difference across R, then  $V = C \times R$ .

Let us suppose that the E.M.F. of H is 10 volts and that the resistance of  $r$  is 10 ohms when the slider is at A and 9 ohms when the slider is at B.

From the above equations we can find the values of C and V for different values of R, first when the slider is at A and then when at B. In this way we can find

the change in  $C$  and the change in  $V$  effected by a given change of 1 ohm in the resistance of  $r$ . For the purpose of easy comparison, the results obtained for three different values of  $R$  can be tabulated as follows :

		Current $C = \frac{E}{R+r}$	Change in Current.	P.D. across $\frac{RV}{C \times R}$	Change in Potential.
$R = 0$ ohms	$r = 10$ ohms	1	} .1	{ 0 }	0
	$r = 9$ ,,	1.1			
$R = 10$ ohms	$r = 10$ ,,	.5	} .026	{ 5 }	.26
	$r = 9$ ,,	.526			
$R = 20$ ohms	$r = 10$ ,,	.333	} .012	{ 6.66 }	.24
	$r = 9$ ,,	.345			

328. To sum up, the greatest *change in the current* for a given change in the grid potential is obtained when there is no resistance in the external circuit; but the greatest *change in the potential* of the circuit under similar conditions is obtained when the resistance of the external circuit is equal to that of the valve.

If we increase the E.M.F. of the sheath battery and at the same time adjust the grid potential so that the current remains constant, we automatically increase the resistance of the valve. Consequently, if the E.M.F. of the sheath battery is infinitely high, the resistance of the valve would also be infinitely high. From this it is clear that the maximum change in the potential of the sheath circuit, for a given change in the potential of the grid when the E.M.F. of the sheath battery is infinitely high, is obtained when the resistance of the sheath circuit is also infinitely high.

329. The power liberated in the sheath circuit is the product of the change in the current and the change

in the E.M.F. It is evident, therefore, that in order to obtain the greatest possible energy effect in the sheath circuit, the transformer primary should be wound to a suitable impedance depending upon the valve and the average frequency of the current. The resistance of such windings is usually of the order of 5000 to 10,000 ohms, and the inductance some two or three henries.

330. Assuming, then, that the external sheath circuit is so designed as to have the most suitable impedance for the valve used, the magnification of power—that is, the ratio of the energy expended on the grid circuit to that liberated in the sheath circuit—will obviously vary according to the design of the valve.

Generally speaking, the maximum energy magnification it is possible to obtain in practice with a single valve, whose magnification constant is 50, is about 10 to 1, although this varies considerably with the different circuits in connection with which they may be used.

331. If the transformer is to be connected to a pair of telephones, then the secondary winding must be wound to a suitable inductance and resistance (*i.e.* impedance) for the particular type of telephones to be used; thus, if high-resistance telephones are used, it is found that the ratio of the transformer should be about 1 to 1, but if low-resistance telephones of about 120 ohms be used, then the ratio of the transformer will be about 5 to 1, the secondary having one turn to every five turns of primary.

#### THE VALVE AS A NOTE MAGNIFIER

Suppose, however, instead of connecting the secondary of the transformer T, Fig. 75, to the telephones, we connect

it across the grid circuit of a second valve, as shown in Fig. 77, it is quite obvious that the magnified E.M.F. variation acting on the second valve will be still further magnified in the sheath circuit, thus producing proportionately louder noises in the telephones if they be connected in this circuit as illustrated.

332. Quite apart from the relative values of the E.M.F. variation in the two grid circuits, it will be observed that whereas the first valve is connected to the aerial circuit and the variation of the grid potential is consequently occurring at radio frequency, the second

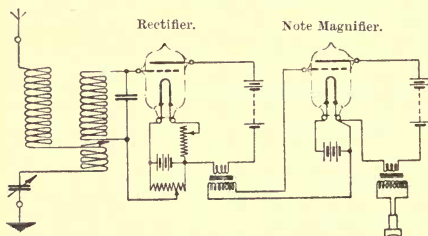


FIG. 77.

valve is connected across the transformer secondary, and the variation of the grid potential is, owing to the rectifying action of the first valve and the capacity

effect of the transformer primary (*vide* paragraph 28), only occurring at note frequency. For this reason a valve used in the manner described in the preceding paragraph is known as a **note magnifier**.

333. Since the variation of the grid potential of the second valve is occurring at note frequency, there is obviously no reason why the normal potential of the grid of this valve should be adjusted to the bend of the curve, because impulses of this frequency are suitable for producing sound in the telephones. In fact, if these low-frequency impulses were rectified in the same way as the high-frequency impulses, the effect would be to



produce a steady current in the telephones without causing the diaphragm to vibrate. It does not follow, however, that this would be the result if the grid potential of the second valve were adjusted to the bend of the curve, because in addition to the rectifying effect it is necessary, as we explained in paragraph 26, to have a suitable reservoir condenser to "flatten out" the pulses. The capacity of the condenser necessary for this process is greater in proportion as the frequency is less, and although the capacity of the windings is, as we have seen, sufficient to flatten out pulses of radio frequency, it would require a very much greater capacity than that to flatten out the rectified note-frequency pulses produced in the sheath circuit of the second valve.

334. Since it is unnecessary for the note magnifier valve to work on the bend of the curve, it is better that its normal grid potential should be well up the steep part of the curve where the greatest magnification is obtained. The potentiometer necessary for this purpose, however, is an additional complication and expense, and is better dispensed with and the sheath circuit connected direct to the negative end of the filament, even though it might be at a small sacrifice of efficiency.

As a matter of fact, in practice, if the grid of the second valve be thus connected, it will usually fall automatically on the steep part of the curve.

335. **The adjustment of the normal grid potential of the first valve does not in any way effect the normal grid potential of the second valve.** The reason for this is that the E.M.F. generated across a transformer secondary depends upon the variation or rate of change

in the primary current, and is therefore quite independent of a steady current flowing through its primary winding. Thus, no matter what the value of the normal current flowing through the primary of the transformer, the E.M.F. across the secondary will be zero until the current is varied by the action of the incoming signal.

336. In Fig. 77 we showed each valve connected to an independent sheath battery and an independent filament battery. We did this to avoid any confusion which might otherwise make the explanation less clear.

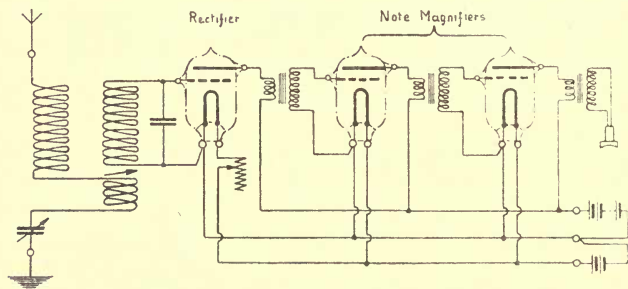


FIG. 78.

There is no reason, however, why both valves should not be connected to the same batteries, and this is always done in practice. Fig. 78 shows the connections of a complete receiver using one valve for rectifying purposes and two for note magnifying.

337. There is one other point which perhaps requires explanation before we leave this subject. It may have suggested itself to some readers that the maximum possible magnification for any particular type of valve could be obtained in one step by increasing the ratio of the first transformer. This, however, is not possible, for reasons similar to those explained in paragraph 323,

namely, the limitations due to the self-capacity of the windings of the transformer.

338. The self-capacity of a telephone transformer winding is, of course, very much greater than that of the jigger secondary, but whereas the oscillations in the latter are of radio frequency, those in the former are only of note frequency, and consequently the effect in the two cases is much the same. The best ratio of transformer to use between the two valves will vary considerably with the type of valve used, but it will usually be somewhere of the order of 1 to 3.

## HIGH-FREQUENCY MAGNIFICATION

339. WITH the use of note magnifiers, signals which would otherwise be extremely weak or even inaudible can be magnified to such a pitch as to be audible from one end of a room to the other. There are, however, several practical considerations which limit the extent to which such magnification can be carried.

340. Chief amongst these is the comparatively poor rectifying efficiency of the valve, or of any other sensitive rectifier, for oscillations of small amplitude (*vide* paragraph 175). Consequently, as we have already noted, strong signals produce results in the telephones out of proportion in their value to those produced by weaker signals. Moreover, if the amplitude of the received oscillations is below a certain value, then, as we noted in paragraph 175, no rectification is effected. Consequently such signals can never be increased by the use of note magnifiers.

341. Another disadvantage of note magnification carried to excess is its sensitiveness to external noises and vibrations. A very small mechanical movement of the grid or filament of the valve is sufficient to alter its constants, with a consequent change in the current passing through it. Thus any slight shock or concussion acting on the first valve of a series of note magnifiers

will set up mechanical vibrations inside the valve sufficient to cause small changes in the current passing through it. **As these changes occur at comparatively low frequency**, each successive valve will greatly magnify the effect, until by the time it reaches the telephones they may be sufficiently loud to drown the signals.

To take a practical case, for example, if a watch be held near the first valve of a receiver using only three note magnifiers, or even if it be lying on the same table as the receiver, the noise produced in the telephones by the tick of the watch will sound like the clang of a hammer striking an anvil.

342. When the valve is used for magnifying high-frequency oscillations, **the circuits are adapted to suit the high-frequency changes in the current**. For example, we know that the inductance of a telephone transformer winding is very much too great to allow high-frequency oscillations to flow through it. On the other hand, the inductance of a jigger or high-frequency transformer winding is so small that note-frequency currents would not produce sufficient magnetic flux to generate any appreciable E.M.F. across the windings. Consequently, if the valves are being used as high-frequency magnifiers, then, owing to the nature of the circuits employed for this purpose, such slow changes in the current flowing through them as might be caused by mechanical vibrations will not be magnified to the same extent.

343. **The advantages of magnifying the radio frequency oscillations induced by the received signals before they are rectified are clearly apparent**. We are no longer pinned down to the bend of the curve for the first valve, but can work on the steep part of the valve



curve, and are thus able to utilise the valve at its utmost efficiency even for the weakest of signals. Weak signals will also be magnified to the same extent as strong signals, and when finally rectified the efficiency of the rectifier will be greatly increased owing to the greater amplitude of the E.M.F. oscillations applied to it.

344. The adaptation of the valve to the purpose of high-frequency magnification is therefore purely a question of designing the external grid and sheath circuits to suit the oscillatory currents; the principles on which the valve itself operates remain unaltered.

#### THE TUNED AMPLIFIER

345. If we connect the grid circuit of the valve as before, either across an aerial tuning inductance or preferably across a secondary oscillatory circuit as shown by A in Fig. 79, and if we connect the sheath circuit of that valve **across another oscillatory circuit** (which for convenience we may term the "sheath oscillatory circuit") as shown by B in the same diagram, it is clear that a steady current of a few micro-amperes will flow from the battery H through the inductance L, its value depending upon the initial potential of the grid. Owing to the fact that the resistance of the coil L is small, the drop in potential across it for a current of a few micro-amperes is negligible. Also owing to the fact that the inductance of L is of the order of a few micro-henries, any low-frequency variations of the current passing through a circuit of such small impedance will cause no appreciable variation of the potential across it, and therefore the potential across the condenser C remains zero.

346. Any high-frequency changes in the current passing through this circuit, however, will be sufficient to cause changes in the potential across the inductance  $L$ , because an inductance of even a few micro-henries offers a considerable impedance to current variations of radio frequency. Thus any increase in the current above its normal value will create a positive potential at the bottom end of the inductance, and charge the condenser  $C$  in one direction; while any decrease in the current below its normal value will create a negative potential at the bottom end of the inductance, charging the condenser  $C$  in the opposite direction.

347. It is easy to see, therefore, that if the cur-

rent variations in the grid circuit  $A$  occur at radio frequency, an oscillatory current **having the same frequency** will be generated in the circuit  $B$ . It is also evident that, owing to the magnifying power of the valve, and provided the impedance of the sheath circuit is suitable, feeble oscillations occurring in the grid oscillatory circuit will cause comparatively powerful oscillations in the sheath oscillatory circuit.

348. The reader should take particular note of the position occupied by the high-tension battery  $H$  in Fig. 79. In the previous diagrams of note magnifiers

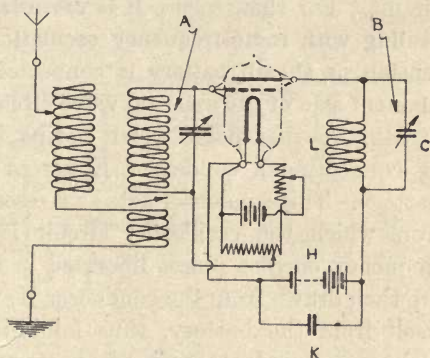


FIG. 79.

we have shown this battery connected directly to the sheath of the valve, and in such instruments no undesirable effect would be noticed, as the currents there dealt with are of comparatively low frequency.

If, however, in the case of the high-frequency circuits we are now considering, the battery H were connected between the sheath of the valve and the inductance L, **the capacity of this battery to earth** would be sufficient to entirely upset the constants of the high-frequency circuit. For this reason, **it is essential when a valve is dealing with radio-frequency oscillations that the high-tension or sheath battery is connected on the earth or filament side of the external valve circuit.**

349. Another point worth noting is the desirability of connecting a condenser K across the high-tension battery. This condenser acts as a reservoir of electricity from which the oscillatory circuit is fed. The high-frequency current pulses liberated in the sheath circuit are then drawn from the condenser K, which recuperates itself from the battery, thus minimising any internal resistance or inductance in the battery.

350. The sheath oscillatory circuit described above will, of course, **have a natural wave-length of its own** depending upon the inductance of L and the capacity of C; therefore, if the circuit be adjusted to the same wave-length as the incoming signal, the oscillations generated in it will build up during a number of cycles to a very much greater amplitude than they would if the circuits were out of tune.

351. In order to detect these magnified high frequency oscillations they must be rectified and "flattened out" in the ordinary way and delivered to a telephone receiver. The rectification can be accomplished by

either a three-electrode valve, a Fleming Valve, or a crystal. In Fig. 80 we show the circuits of the receiver described above, connected to a three-electrode valve detector, while in Fig. 81 we show the same receiver connected to a crystal detector.

352. If a valve be used as the detector, it will be observed that it cannot be connected directly across the sheath oscillatory circuit on account of the fact that the E.M.F. of the high-tension battery H would be acting

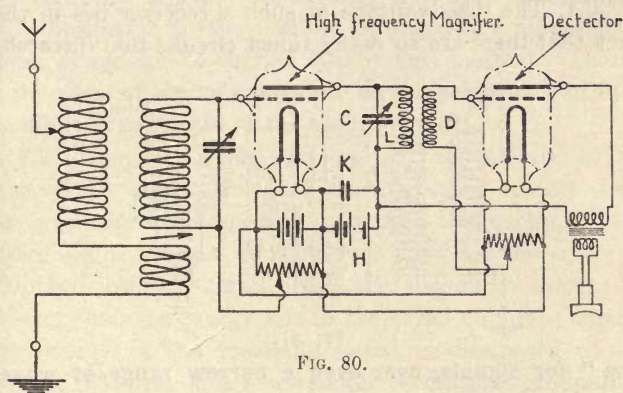


FIG. 80.

directly across the detector. This can be avoided either by using independent batteries or by magnetically coupling another winding, as shown by D in Fig. 80, to the sheath oscillatory circuit of the magnifier, and connecting the detector across it. Provided the two circuits are properly insulated from one another, then an E.M.F. will be induced across the detector only when there is a change in the E.M.F. across the sheath oscillatory circuit, and consequently the detector is entirely unaffected by any steady current flowing through the sheath circuit or by the steady E.M.F. of the battery H.

353. If the winding D, to which the detector is con-

nected, is only loosely coupled to the sheath oscillatory circuit, then it would necessarily have to be tuned to the same wave-length, but if the two circuits be very closely coupled the tuning of the detector circuit can be dispensed with, as the two circuits will act to all intents and purposes as one. In practice, therefore, the detector winding D and the oscillatory circuit winding L are both wound on the same former, the one immediately over the other.

354. The disadvantage of such a receiver lies in the fact that **there are so many tuned circuits that "search-**

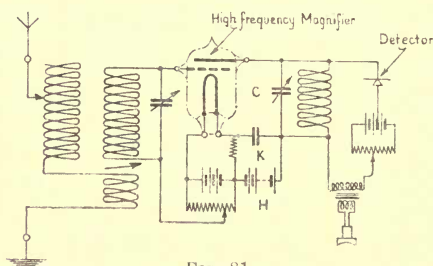


FIG. 81.

ing" for signals, over even a narrow range of wave-lengths, becomes a matter of some difficulty when more than one high-frequency magnification is attempted. Thus in the receiver illustrated in Figs. 80 and 81 there is the aerial circuit, the jigger secondary circuit, and the sheath oscillatory circuit, all of which must be adjusted to resonance with the incoming signal. We can eliminate one of these tuned circuits, namely, the jigger secondary, and connect the grid of the first valve directly across the aerial tuning inductance, but if, as is often the case, it is desired to magnify the received oscillations to a far greater extent, we may require as many as five or even ten high-frequency magnifiers.



If each of these requires a tuned sheath circuit, then it becomes a practical impossibility to search for signals over any range of wave-lengths, in addition to which the cost of manufacturing such a receiver becomes excessive. The difficulty can be overcome to a certain extent by mechanically coupling up all the tuning condensers of the several sheath circuits, enabling them to be operated synchronously by a single handle; this, however, is cumbersome and extremely costly.

355. The difficulty of tuning, however, is not the only limitation to the number of successive magnifications which can be carried out by this method. There is **the effect of the magnification on the persistence of the oscillations generated in the sheath circuits.**

356. The oscillations set up in the circuits of a receiver by signals received from a spark transmitter are gradually built up during the first few cycles. The building-up process continues so long as the energy absorbed by the aerial from the incoming waves is greater than the energy lost in the aerial circuit. When the energy in the receiving aerial is dissipated at a greater rate than it is received the oscillations gradually die out. From this it is easy to see that the greater the length of the incoming train of waves acting on the receiving aerial, *i.e.* the less the damping of the received waves, the longer will the building-up process last.

357. The length of time taken for the train of oscillations generated in the receiving aerial to die out, however, depends upon the damping of the circuit. Thus if there were no damping in the circuit a single received impulse would generate oscillations which would continue for ever at the same amplitude. A group of damped waves would build up oscillations in the receiving aerial which

would reach their maximum amplitude when the received waves had died out, and would then continue to oscillate at this amplitude for ever.

358. In practice, however, when a detector is connected directly across the aerial circuits, the damping of the circuit, due partly to its resistance, partly to the radiation of waves, and partly to the work done on the rectifier, is such that the length of time occupied by a group of oscillations created in the aerial by a spark signal is never more than about one-tenth of the time interval between successive sparks.

359. But if, as in the case of the high-frequency amplifier we are now considering, the group of oscillations is magnified and impressed on another oscillatory circuit, then, assuming that the damping of this circuit is less than that of the aerial, not only will the oscillations have a greater amplitude, but also a greater persistence.

It will easily be seen that **for the reception of spark signals the magnification cannot to advantage be carried beyond the point where one group of oscillations generated by a single spark at the transmitter just dies out before the next group commences** (*vide* paragraphs 36 to 40).

### THE RESISTANCE AMPLIFIER

The ideal high-frequency magnifier is obviously one which is absolutely aperiodic, that is to say, which is equally sensitive to E.M.F. variations of all frequencies. Then the whole of the tuning of a receiver to which it is connected can be accomplished in the ordinary way by tuning the aerial circuit—and if desirable also a secondary circuit—to the desired wavelength.

360. Thus the sifting out of all wave-lengths other than the one it is desired to receive should be effected by what for convenience we may call the “**receiver circuits**”; the sifted result would then be passed to the “**amplifier**,” where the amplitude of the oscillations would be increased; finally the magnified oscillations would be passed to what we may call the “**detector circuits**,” consisting of a rectifier and telephones, and possibly one or more note magnifiers to increase the volume of sound.

361. The whole scheme, however, depends upon our ability to make the circuits of the high-frequency magnifiers aperiodic, or at all events as nearly aperiodic as possible. But it is obviously desirable also that we obtain the maximum possible magnification with each valve, in order to reduce the number of valves required for a given total ratio of magnification to a minimum.

362. Suppose, for the sake of simplifying the adjustments of a receiver, we cut out all adjustments to the amplifying circuits. Then, whether or not we connect a condenser across the inductive windings of the circuits, by reason of their inductance and self-capacity they form oscillatory circuits and have *ipso facto* a time period of their own. If, then, the sheath circuit of the high-frequency magnifier is periodic, and if its natural frequency instead of being adjustable is fixed at a certain value, although the “receiver circuits” may be tuned to the incoming signal, **the receiver as a whole will be extremely sensitive to signals whose wave-length is the same as that of the magnifier circuits, and very insensitive to all other wave-lengths.**

363. If we were to plot a curve to show the sensitive-

ness of a receiver fitted with a tuned amplifier to signals of different wave-lengths, and if the tuning of the sheath circuit of the magnifier were fixed at a definite wave-length, say 600 metres, it is easy to see that the curve would take the same shape as the ordinary resonance curve illustrated in Fig. 19. Such a curve is shown in

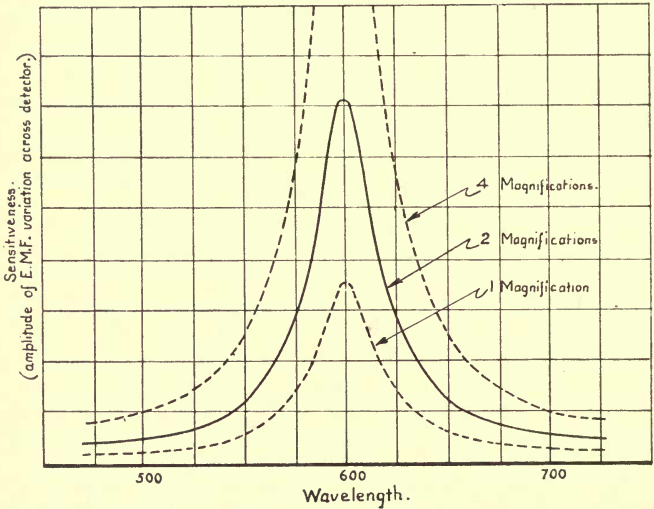


FIG. 82.

Fig. 82, where we have plotted the amplitude of the potential variation across the sheath of the final valve, instead of sensitiveness, as the latter term is liable to lead to misunderstanding. This curve takes into consideration not only the damping of the receiver, but also that of the received signal, and we have assumed that in each case this is of the average order met with in practice.

The use of a greater or less number of magnifiers will only alter the height of the curve without altering its proportions; thus the two dotted curves in Fig. 82 illustrate the results which would be obtained if twice the number and half the number respectively of high-frequency magnifiers were used.

364. If, then, to avoid the difficulty and inconvenience of individual adjustment of each circuit, the high-frequency magnifier employed with a receiver had the windings of its sheath circuits fixed at a definite value, the curve illustrated in Fig. 82 would be **the characteristic sensitiveness curve of the receiver** as a whole. The ideal characteristic sensitiveness curve would be a straight line parallel to the abscissae, and the objections to a curve of the shape shown in Fig. 82 are sufficiently obvious to need no further explanation.

365. Before we examine the possibilities of an aperiodic amplifier, let us be quite sure that we have fully grasped the particular work which the magnifying valves are required to perform.

When we use a train of high-frequency magnifiers, the purpose of each valve is to magnify the amplitude of the E.M.F. oscillations which are applied to its grid, and to impress these magnified oscillations on the grid of the next valve.

366. The greatest magnification of E.M.F. is obtained, as we have noted, when the resistance of the external circuit is infinitely high, and under these conditions the magnification obtainable with a single typical valve is of the order of 60 to 1.

If we could connect our train of valves as shown in Fig. 83, we could not only obtain the greatest possible magnification on each valve, but the circuits of each



valve would be absolutely aperiodic, and consequently no tuning of these circuits would be necessary.

367. This method, however, is impracticable for various reasons. For instance, the direct connection of the high-tension sheath battery of the first valve to the

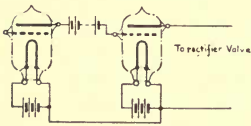


FIG. 83.

grid of the next valve would raise the potential of the latter to such a value as to stop all flow of current through the second valve.

A modification which we show in Fig. 85, however, overcomes this difficulty, and in this form the arrangement constitutes what is undoubtedly the most perfect form of high-frequency amplifier for spark signals, inasmuch as it is absolutely aperiodic and enables one to obtain the maximum possible magnification from the valve. It suffers, however, from the defects of requiring a separate high-tension battery for each valve, and of being tricky to adjust.

368. The explanation of the arrangement will be better understood if we

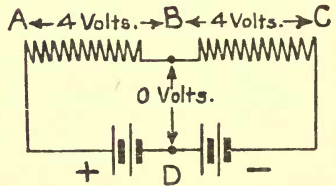


FIG. 84.

first analyse the differences in potential between different points of a simple electrical circuit consisting of a battery shunted by a resistance. Suppose, then, we connect two equal resistances AB and BC in series across an 8-volt battery, as shown in Fig. 84, it is obvious that whatever the value of these resistances so long as they are equal there will be a drop of 4 volts across each. Further, if they are connected as shown

in the diagram, the point A will be 4 volts positive to the point B, and similarly the point C will be 4 volts negative to the point B. It is clear, therefore, that under these conditions the point B is at zero potential to the middle of the battery D. Further, if one of these resistances be kept constant, any variation in the value of the other will cause a variation of the potential between B and D.

369. Now the resistance of a valve can be calculated from Ohm's Law  $R = \frac{E}{C}$ . It is clear, therefore, that the

resistance of a given valve depends upon the filament brilliancy, the sheath potential, and the grid potential. Thus, if we take the case of the valve whose characteristic curves are illustrated in Fig. 62, we find that when the filament brilliancy is normal and the sheath potential is 100 volts, the current flowing through the valve when the grid potential is 1 volt is about 200 micro-amperes. The resistance of the valve under these conditions is therefore  $\frac{100}{200 \times 10^{-6}} = 500,000$  ohms.

370. Suppose, then, we connect a resistance of 500,000 ohms in series with this valve, as shown by R in Fig. 85, then assuming that the battery H is 200 volts and the potential of the grid is adjusted to +1 volt, it is clear that since the resistance of R is equal to that of the valve, the potential between the sheath of the valve and the middle of the high-tension battery, D, is zero.

371. In this way we may connect the grid and filament of the second valve to the sheath and **the middle of the high-tension battery** of the first valve, as shown in the diagram. By adjusting the potential of the grid of the first valve we vary its resistance, and in this way we can

vary the initial potential of the second valve to any desired point on the curve. Thus, if the second valve is used as a rectifier, as shown in the diagram, its normal grid potential would be adjusted to the bend of the curve, but if it were to be used for still further magnification of the high-frequency oscillations, its initial potential would be adjusted to a steeper part of the curve.

372. Owing to the fact that a very small change in the grid potential of the first valve makes a very big change in its resistance, as can be seen by referring to

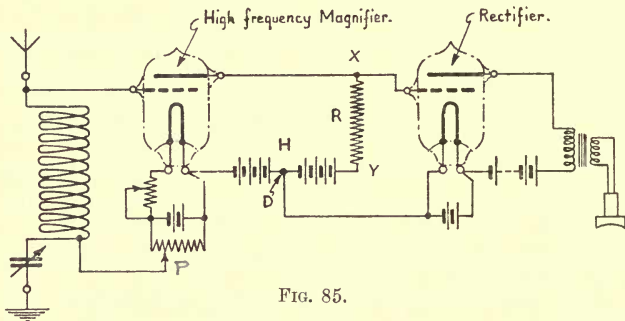


FIG. 85.

the characteristic curve in Fig. 62, the adjustment of the potentiometer P requires the greatest care. The filament brilliancy also has a similar effect on the resistance of the valve, and for this reason the circuits are difficult to adjust and to maintain in adjustment except under ideal conditions.

373. In the foregoing paragraphs we have explained the action of the valve with reference to the circuits in question by considering it as a variable resistance. We did so because it was by far the simplest way of explaining the principle of its application to that particular circuit.

The student must not, however, imagine that we have introduced a new variable factor of which he has no knowledge. The resistance of a valve, as already noted, is calculated in the ordinary way by Ohm's Law, and since a variation of the grid potential causes a certain variation in the current flowing through the sheath circuit although the sheath potential remains constant, it follows that **the resistance of the valve for a given sheath potential varies with the grid potential.**

374. To prevent any confusion, let us look at the same experiment from another point of view. If we connect a resistance in series with the sheath circuit, as shown by R in Fig. 85, it is evident that since a change in the grid potential of the valve causes a change in the current flowing through this resistance, there will consequently be a change in the potential across the resistance, which again can be found by applying Ohm's Law. It is also obvious that if there is a change in the potential between X and Y, there is exactly the same change in the potential between X and D, and it is across these two points that the grid circuit of the second valve is connected.

375. There is another limitation to this type of amplifier, namely, **the effect of the capacity of the valve** which renders the arrangement useless for short wave-lengths. The reason for this requires some explanation.

376. If, as we have assumed in the circuits illustrated in Fig. 85, the resistance of R is absolutely non-inductive, then the drop in potential across it due to **any variation in the current flowing through it** will be quite independent of the frequency of these variations. It would seem, therefore, that the "sensitivity curve" of the amplifier for different wave-lengths should take the form of a

straight line parallel to the abscissae, as shown by the dotted line in Fig. 86. This would be the case if there were no capacity in the circuit. But, as we have already noted, the valve itself has a certain capacity between

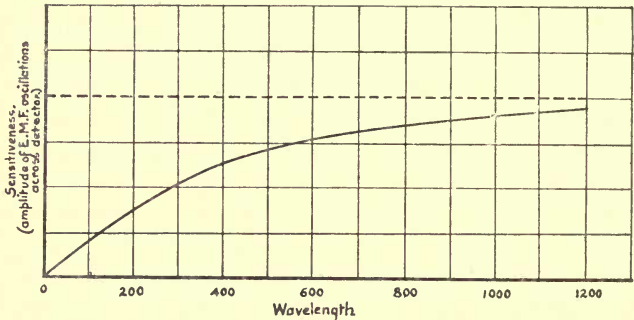


FIG. 86.

the sheath and the filament, and in addition to this there is necessarily a certain amount of capacity in the resistance  $R$ . Although these capacities are extraordinarily small they are sufficient to act as a "cushion" to current variations of extremely high frequencies, with the result that in practice the sensitiveness curve of the amplifier falls off rapidly for short wave-lengths, as shown by the full line curve in Fig. 86.

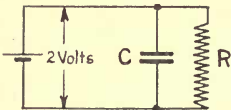


FIG. 87.

377. The explanation of this effect of capacity in the circuit is easily understood if we take a simplified example. If we shunt a resistance  $R$  by a condenser  $C$ , as shown in Fig. 87, and apply a steady potential across it, the value of the current flowing through  $R$  can be found by Ohm's Law. If the resistance of the source of current were zero, the



effect of the condenser C, no matter what its capacity, would be negligible. Thus if the resistance of R is 10 ohms, and the potential applied across it 2 volts, the current flowing through the resistance is  $\frac{2}{10} = .2$  ampere.

378. If we analyse what takes place in such a circuit, it is evident that immediately the potential of two volts is applied there is a momentary rush of current into the condenser C, charging it instantaneously to a P.D. of 2 volts. The quantity of electricity which flows into C depends upon its capacity, but since the resistance of the source of current is assumed to be zero, an infinitely large current can flow into the condenser, and consequently the length of time taken for it to become charged to the full potential is also zero. After this first momentary rush of current into the condenser a steady current of .2 ampere will flow through the resistance R.

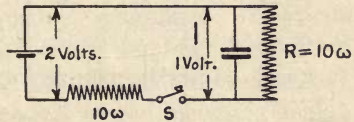


FIG. 88.

379. Now let us suppose that the internal resistance of the source of current is also 10 ohms, which, for the sake of clearness, we have shown outside the battery in Fig. 88. It will be seen that when the switch S is closed only .1 ampere can flow through the resistance R, because the total resistance of the circuit is now 20 ohms, and owing to the drop in potential of 1 volt across the internal resistance of the battery, the E.M.F. applied across R is only 1 volt.

380. Also it is obvious that in this case the condenser C cannot become instantaneously charged to the full potential across R, because the rate at which electricity

can flow into it is limited by the internal resistance of the battery. Thus the maximum flow of current into the condenser when the switch is first closed cannot exceed  $\cdot 2$  ampere.

381. It is evident, therefore, that the condenser C will in this case **gradually become charged** to the full potential of 1 volt, with the result that the E.M.F. across R, and also the current flowing through it, only gradually rises to its full value. It follows that if the

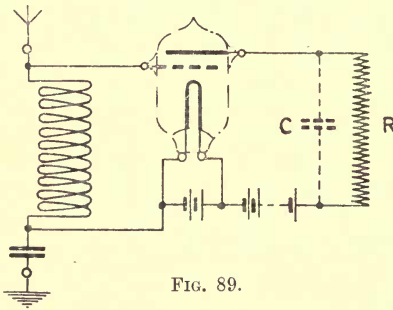


FIG. 89.

switch S is opened before the condenser has had time to become fully charged, the E.M.F. across the resistance R will not reach the full value of 1 volt, and that the shorter the length of time that the switch is closed

the lower will be the rise in E.M.F. across the resistance for a given applied E.M.F.

382. Exactly similar conditions prevail in a valve circuit such as that shown in Fig. 85, which for clearness we have reproduced in a simplified form in Fig. 89, where a resistance R is connected in the sheath circuit. The capacity of the valve and also that of the resistance itself can be considered as a small condenser C connected across the resistance. The internal resistance of the valve corresponds with the internal resistance of the battery in the experiments just explained, while the variation of the grid potential due to the incoming signal corresponds with the opening and shutting of the switch S.

383. It is easy to see that, provided the frequency of the received oscillations is low enough to allow the condenser to become fully charged during one half-cycle, the maximum possible P.D. for a given strength of signal will be created across the resistance. But if the frequency of the received oscillations is greater than a certain value, then the P.D. created across the resistance for a given strength of signal will be smaller and smaller as the frequency is increased, as shown by the full line curve in Fig. 86.

#### THE SEMI-APERIODIC AMPLIFIER

384. We have described in the preceding paragraphs two types of high-frequency magnifiers. The one which we have termed the "tuned amplifier" is limited in its useful application by the fact that it is necessary to tune each amplifying circuit to the incoming signal. The other, which we have termed the "resistance amplifier," is limited in its useful application by the difficulty of maintaining it in uniform adjustment, by the necessity of employing an independent high-tension battery for each valve, and by the rapid reduction of magnification for wave-lengths less than about 1000 or 1500 metres.

There are many other modified forms of these two arrangements, which in principle do not differ materially from those described, and we do not, therefore, propose to deal with them in this book.

385. There is, however, one modification which brings into play a combination of factors with the object of eliminating as far as possible the deficiencies of the resistance magnifier just described, although these

features are obtained somewhat at the expense of efficiency. Efficiency, however, is not usually of paramount importance, because so long as the amplifier is uniformly inefficient over a reasonable range of wave-lengths, and so long as the use of additional magnifiers does not complicate the adjustment of the instrument, inefficiency can be allowed for by employing one or more additional valves to bring the sensitiveness of the receiver up to the desired pitch. The type we refer to is what may be termed, for convenience, the "semi-periodic amplifier."

386. Referring again to Fig. 89, it should be sufficiently clear without further explanation that **up to a certain point the greater the ohmic resistance of R the greater will be the resulting variation of potential across it** for a given variation of the grid potential, provided, of course, we increase at the same time the E.M.F. of the high-tension battery in proportion. Increasing its ohmic resistance, however, would not make it proportionately more sensitive to short wave-lengths.

387. Suppose, however, instead of making the resistance absolutely non-inductive, we wind it like an ordinary jigger, except that we use wire of a very high resistance. It is obvious that under these conditions the circuit will have a natural time period of its own depending upon its inductance and self-capacity, **and will, therefore, be particularly sensitive to wave-lengths in tune with its own natural time period** (*vide* paragraph 350).

388. A circuit designed on these lines is illustrated diagrammatically in Fig. 90, where J is the high-resistance inductive winding connected in the sheath circuit of the amplifying valve. Neglecting for the moment the



effect of the natural time period of the circuit, it will be easily seen that owing to the resistance of *J* the sensitiveness curve of the amplifier, *i.e.* the drop across *J* due to its resistance only, would try to take the form of the curve illustrated in Fig. 86. On the other hand, neglecting the drop across *J* due to resistance, the sensitiveness curve of the amplifier due to the natural time period of *J* would try to take the form of the curve illustrated in Fig. 82 (*vide* paragraph 363), except that

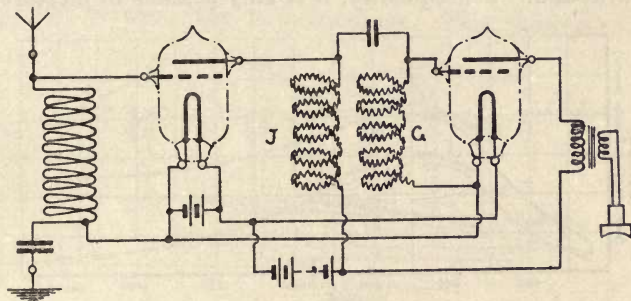


FIG. 90.

its peak would be considerably flattened owing to the high damping of the winding *J*.

389. The net result is that the actual form the curve takes is the sum of the two effects and is illustrated in Fig. 91, where for the sake of clearness we have indicated by a dotted line the sensitiveness due to the resistance effect, and by a thin line that due to the resonance effect. Although the curve is not absolutely uniform it will be observed that it is sufficiently uniform for all practical purposes over a considerable range of wavelengths, and by suitably winding the jiggers the "hump" of the curve can be made to come at any desired wave-



length. Thus in the example illustrated in Fig. 91 the variation in sensitiveness between wave-lengths of 550 metres and 1500 metres would not be sufficient to cause serious inconvenience.

390. A point that should be noted in connection with this type of magnifier is that the dimensions of the winding J, *i.e.* the diameter of the former and the number of turns, is controlled by the wave-length to which, for reasons explained in paragraph 381, it must be wound. Consequently, it is only possible to increase

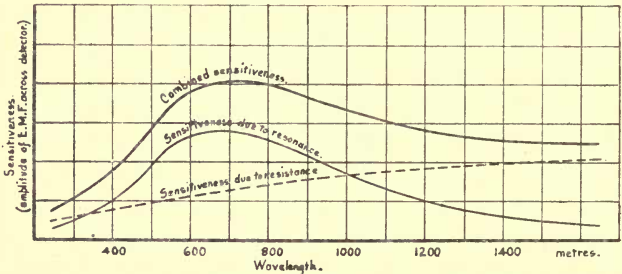


FIG. 91.

the resistance of the winding by reducing the size of the wire and by choosing a material having very high specific resistance. Owing to these limitations when the amplifier is designed for short wave-lengths, it is very difficult to obtain a sufficiently high resistance to give the maximum sensitiveness due to resistance obtainable with the resistance magnifier (*vide* paragraph 386). Consequently the same design is very inefficient for long wave-lengths.

391. It now only remains to be seen how the magnified variation in the potential across the amplifier circuits can be communicated to the next valve. If we mag-

netically couple a secondary circuit G to the winding J by winding the one coil immediately over the other, and if we connect the winding G as shown in the grid circuit of the next valve, the magnified E.M.F. oscillations due to the oscillations which are built up in J (by reason of its resonance with the incoming signal) will be communicated through the mutual inductance of the two windings to G, but the magnification due to the resistance of J will not be reproduced in G unless there is mutual capacity between the two windings. This, however,

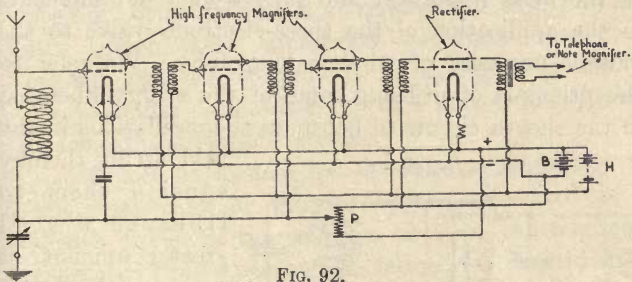


FIG. 92.

can be supplied by connecting a condenser C across the insulated ends of the two windings as shown in Fig. 90.

392. With such circuits there is nothing to prevent our using the same filament battery and the same high-tension battery for all valves. In Fig. 92 we show the diagram of connections of a three-valve high-frequency magnifier designed on these lines and connected on one side to an ordinary single circuit receiver, and on the other side to a rectifier or detector. The rectifier can of course be connected either direct to the telephones or to a series of note magnifiers.

## THE REACTION PRINCIPLE

393. WE are now in a position to consider what is one of the most important and far-reaching developments in the application of the three-electrode valve to the various purposes of wireless telegraphy. We refer to the principle of utilising some of the energy liberated in the sheath circuit to boost up the oscillations in the

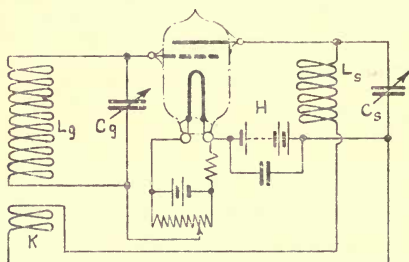


FIG. 93.

grid circuit, thereby causing them to liberate a still greater amount of energy in the sheath circuit.

The principle is somewhat analogous to that employed in a machine-gun, where some of the

energy liberated in the barrel by the explosion of the cartridge is utilised to eject the empty cartridge, reload the gun, and fire the next cartridge.

394. Let us take an elementary case, as illustrated in Fig. 93, where one oscillatory circuit,  $L_g, C_g$ , is connected across the grid and filament of a valve, and another oscillatory circuit,  $C_s, L_s, K$ , is connected

across the sheath and filament of the same valve, through a high-tension battery H. Owing to the mutual inductance between K, usually known as the reaction coil, which forms part of the sheath oscillatory circuit, and  $L_g$ , which forms part of the grid oscillatory circuit, it is evident that any current oscillations in the former will induce similar oscillations in the grid circuit.

395. First of all let us suppose that the coupling between the reaction coil and the grid oscillatory circuit is adjusted to zero, either by moving the coil to a remote position, or by turning it at right angles to the winding  $L_g$ . Under these conditions we know that feeble current oscillations induced in the grid circuit will create similar oscillations, but of a greater amplitude, in the sheath oscillatory circuit.

396. Let us assume for the sake of simplicity that the persistency of the oscillations generated in the sheath circuit is the same as that of the oscillations generated from some outside source in the grid circuit. In Fig. 94 we have illustrated diagrammatically the oscillations generated in the sheath circuit from some outside source, and which owing to the loss of energy due to resistance, etc., die out after a few cycles.

397. If now we bring the reaction coil K nearer to the grid circuit so that some of the energy liberated in the sheath circuit is transferred, through the mutual inductance of the two windings, to the grid circuit, it is easy to see that the energy thus transferred will make up for at least some of the energy lost in the grid circuit, with the result that the persistency, and also to some extent the amplitude, of the oscillations in the grid

circuit will be increased, thereby also increasing the persistency of the oscillations in the sheath circuit. Assuming that the strength of the impulses given to the grid circuit is the same as before, the resulting oscillations in the grid oscillatory circuit will be as

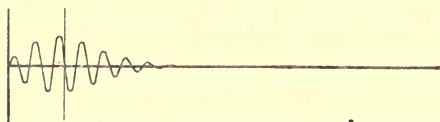


FIG. 94.

shown in Fig. 95. The effect of this coupling is therefore practically the same as if the damping in the grid circuit were reduced.

398. If the coupling between the sheath circuit and the grid be still further increased, then it is clear that a stage will be reached when the loss of energy in the

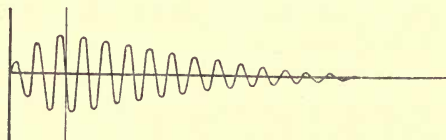


FIG. 95.

grid circuit is entirely made good by the amount of energy transferred from the sheath circuit to the grid circuit, and under these conditions it is obvious that any oscillations started in the grid circuit will continue indefinitely, as shown in Fig. 96. Consequently the magnified oscillations in the sheath circuit will also continue indefinitely. The grid oscillatory circuit will then act as though it had no damping, and therefore the



smallest impulse given to the sheath oscillatory circuit will be sufficient to start the oscillations.

399. Under these conditions the valve is said to be "oscillating," and although this is a convenient expression to use, it is not, strictly speaking, accurate. It is only the current in the two oscillatory circuits which is oscillating, because although the current through the valve increases and decreases at radio frequency, its direction, for obvious reasons, never reverses.

400. In this explanation we have assumed that both the grid and sheath oscillatory circuits are tuned.

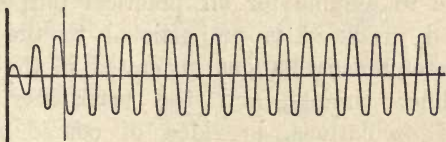


FIG. 96.

This is not necessary in practice, because since the frequency of the impulses produced in the sheath circuit depends upon the frequency of the E.M.F. variations of the grid, it is evident that they must both necessarily keep the same. So long as one of these circuits is a tuned circuit, the frequency at which the valve will oscillate will correspond with the natural frequency of that circuit, and oscillations of this frequency will therefore be forced on the other circuit.

401. The principle of reaction can be most usefully employed not only for the purpose of increasing the sensitiveness of the valve as a detector, but also as a means of generating continuous oscillations of a uniform

amplitude, and can therefore be used for heterodyne reception and for the transmission of continuous wave signals.

#### USE OF REACTION FOR RECEPTION OF SPARK SIGNALS

402. The strength of the sound produced in the telephones is a very complex matter to determine exactly, as it depends upon so many factors, such as total change in the current flowing through the coils, the rate of this change, the frequency of the changes, the inertia of the diaphragms, and many other things. It is safe to assume for all practical purposes that the sound produced is proportional to the **average amplitude of the oscillations** generated in the receiver or amplifier circuits, and the **persistency of the group** of oscillations, provided of course that one group of oscillations dies out before the next group commences.

403. Now **the extent to which the amplitude of the oscillations can be increased by reaction between the sheath and grid circuits is very limited**, especially in the case of weak signals. Except during the building-up process, each successive cycle must be of smaller amplitude than the preceding one to enable one group to die out before the commencement of the next. It will be observed, however, that the greater the number of cycles occupied in the building-up process (which depends, as we have seen, upon the damping of the received waves) the greater will be the total increase in amplitude obtainable by the reaction method. The chief advantage in the reaction method lies in the increase which can be obtained in the persistency of the

received oscillations, thereby enabling a greater amount of energy to be liberated in the sheath circuit and used by the telephones.

404. If the principles underlying the use of reaction have been thoroughly understood, the student will have no difficulty in following the connections of different types of spark signal receivers employing this means of increasing their sensitiveness. Fig. 97 shows the connections of a single circuit receiver in which a three-electrode valve is used

purely as a rectifier or detector. In this case the sheath circuit is not oscillatory, but although the current passing through the reaction coil is consequently

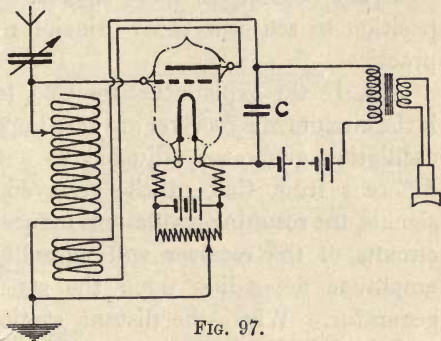


FIG. 97.

unidirectional, its value is changing at radio frequency of the same periodicity as that of the aerial circuit, and is therefore just as suitable for boosting up the oscillations in the grid circuit.

405. It will be noticed in the diagram (Fig. 97) that a condenser C is shown connected across the high-tension battery and telephone. The object of this condenser is to facilitate the passage of the high-frequency impulses through the sheath circuit which would otherwise have to flow through the battery itself. The condenser, being connected across the battery, is maintained fully charged to the potential of the battery, and thus acts as a reservoir

of electricity containing a sufficient quantity to supply the necessary high-frequency current impulses to the sheath circuit.

#### INDEPENDENT HETERODYNE METHOD OF DETECTING CONTINUOUS WAVE SIGNALS

In paragraphs 44 to 69 we explained at some length the principles underlying the "Beat" method of receiving continuous wave signals. We are now in a position to see how these principles can be applied in practice.

406. In the explanation referred to, we showed that if the circuits of a receiver are acted upon by a continuous oscillation generator adjusted to a frequency slightly different from that of the received continuous wave signals, **the resulting oscillations induced in the oscillatory circuits of the receiver will normally have a uniform amplitude** depending upon the strength of the local generator. When the distant station is transmitting and the E.M.F. thereby generated in the aerial is superimposed upon the local oscillations, **the resulting oscillations will have a varying amplitude**, the variation depending upon the strength of the received signals. We also showed that if these oscillations having a varying amplitude are impressed on a suitable rectifier circuit, such as a valve and telephone, the current through the telephones will alternate at a frequency corresponding to the difference between the frequency of the local generator and the frequency of the received oscillations.

407. In describing the effect of reaction between the sheath and grid circuits of a three-electrode valve, we pointed out in paragraph 398 that if the coupling

between the reaction coil and the grid circuit is above a critical value, any impulse acting on the grid circuit is sufficient to start continuous oscillations in both circuits. By setting up a similar circuit to that shown in Fig. 93 we are provided with a radio-frequency generator which we can use to excite our receiver circuits, and which we can arrange with suitable adjustments to generate oscillations of any desired wavelength.

408. Suppose, then, we set up such a circuit, as

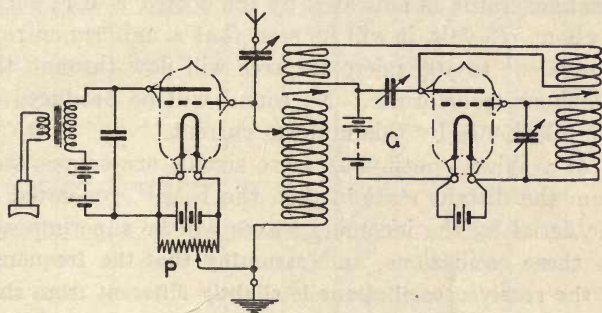


FIG. 98.

shown by G, Fig. 98, so that either its grid or sheath circuit is inductively coupled to the aerial circuit of a receiver. It is clear that in these circumstances, if we start the generator G oscillating, it will generate oscillations of the same frequency in the aerial circuit of the receiver.

409. By varying the coupling between the local generator G and the aerial circuit of the receiver, and by adjusting the tuning of the oscillatory circuits of the local generator, we can obtain oscillations of any desired amplitude and frequency in the aerial circuit of the



receiver quite independent of the wave-length to which the aerial may be tuned.

410. If the grid potential of the receiver valve is adjusted by the potentiometer P to some point near the bend of the characteristic curve, as shown by X in Fig. 99, then a uniform unidirectional current will flow through the telephone transformer having a value depending upon the amplitude of the oscillations generated. Thus in the case illustrated in Fig. 99, where the amplitude of the oscillations induced by the local generator as indicated by the dotted E.M.F. curve is about .75 volt, it will be seen that a uniform current equivalent to 100 micro-amperes will flow through the telephone transformer. No sound will be produced in the telephones by this uniform current.

411. When continuous wave signals are transmitted from the distant station, then the E.M.F. generated in the aerial by the incoming waves will be superimposed on these oscillations, and **assuming that the frequency of the received oscillations is slightly different from that due to the local generator**, the resulting oscillatory E.M.F. acting on the grid will, as we have seen, vary in amplitude from a maximum equal to the sum of the two amplitudes to a minimum equal to the difference of the two amplitudes. Thus the full line E.M.F. curve in Fig. 99 illustrates the resulting oscillations if the amplitude of the received oscillations is .25 volt. From this it will be seen that, provided the frequency of the amplitude variation is suitable, the current flowing through the telephone transformer will vary at note frequency between the points B and B<sub>1</sub>, *i.e.* in the case illustrated by an amount equivalent to the difference between 75 micro-amperes and 130 micro-amperes.

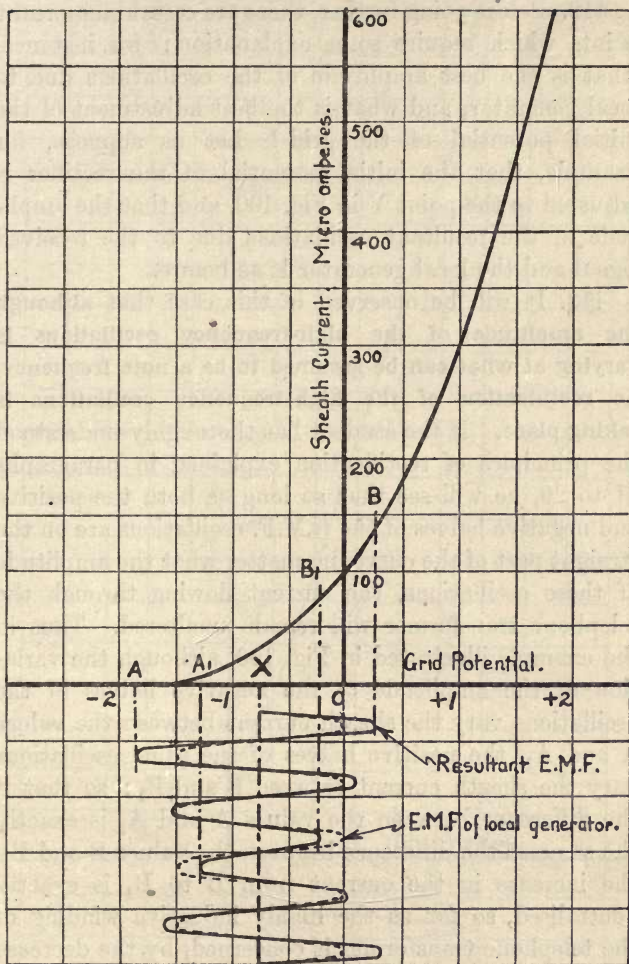


FIG. 99.

412. Before going further, there are certain important points which require some explanation; for instance, what is the best amplitude of the oscillations due to local generator, and what is the best adjustment of the initial potential of the grid? Let us suppose, for example, that the initial potential of the rectifier is adjusted to the point Y in Fig. 100, and that the amplitude of the resultant oscillations due to the received signal and the local generator is as before.

413. It will be observed in this case that **although the amplitude of the high-frequency oscillations is varying at what can be assumed to be a note frequency, no rectification of the high-frequency oscillations is taking place.** If the student has thoroughly understood the principles of rectification explained in paragraphs 11 to 29, he will see that so long as both the positive and negative halves of the E.M.F. oscillations are on the straight part of the curve, no matter what the amplitude of these oscillations, the current flowing through the telephone transformer will remain unaltered. Thus in the example illustrated in Fig. 100, although the variation of the amplitude of the negative halves of the oscillations vary the sheath current between the values A and  $A_1$ , the positive halves of the same oscillations vary the sheath current between B and  $B_1$ ; so that if the difference between the values A and  $A_1$  is exactly the same as the difference between the values B and  $B_1$ , the increase in the current from B to  $B_1$  is exactly neutralised, so far as the highly inductive winding of the telephone transformer is concerned, by the decrease in the current from A to  $A_1$ .

414. In the case illustrated in Fig. 99, however, **where the normal potential of the grid is adjusted to a**

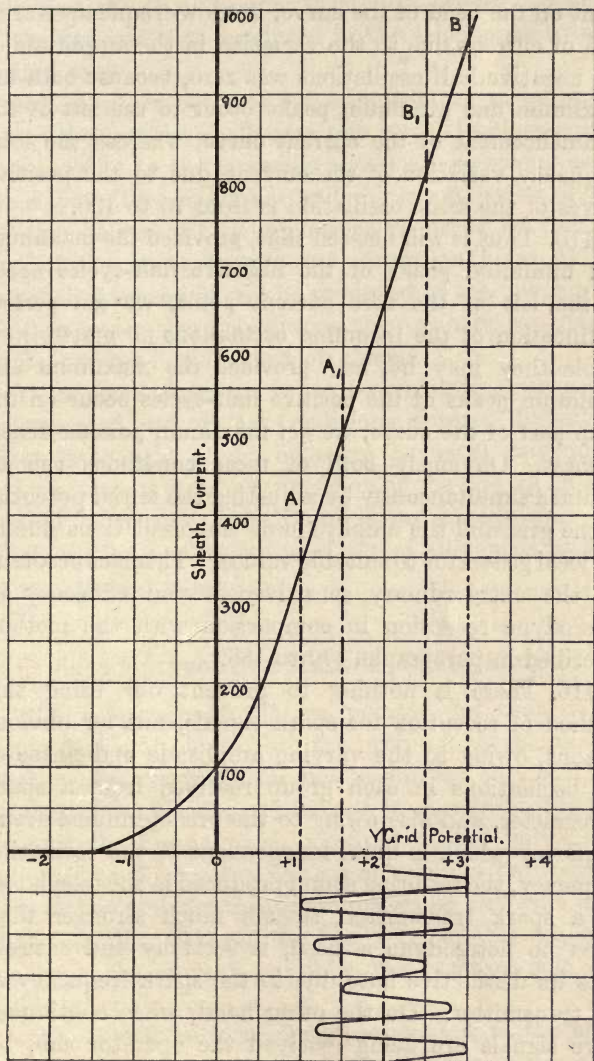


FIG. 100.

point on the bend of the curve, the low-frequency variation of current due to the variation in the amplitude of the negative half oscillations was zero, because both the maximum and minimum peaks occur to the left of the commencement of the current curve, whereas the low-frequency variation of the current due to the positive halves of the same oscillation is from 75 to 130.

415. Thus it will be seen that, provided the maximum and minimum peaks of the negative half-cycles occur to the left of the zero current point, we get perfect rectification of the incoming oscillations no matter how feeble they may be, and provided the maximum and minimum peaks of the positive half-cycles occur on the steep part of the curve, we get maximum possible sensitiveness. Obviously both of these conditions can be obtained simultaneously by adjusting the initial potential of the grid and the amplitude of the oscillations due to the local generator to suitable values. This fact accounts for the extraordinary sensitiveness and efficiency of heterodyne reception in comparison with the method described in paragraphs 170 to 186.

416. There is nothing to prevent our using this method of reception for spark signals, but for obvious reasons, owing to the varying amplitude and phase of the oscillations in each group received from a spark transmitter, and also owing to the predetermined group frequency which is quite independent of the oscillation frequency, the resulting sound produced in the telephones by a spark transmitter, though much stronger than when no heterodyne is used, is scratchy and entirely loses its distinctive note due to the spark frequency of the transmitter. On the other hand, when continuous wave signals are being received the operator can, by



adjusting the local generator circuits, adjust the pitch of the musical note produced in the telephones to any desired tone.

417. Another point of some importance to be noted is that if either the oscillations due to the local generator or those due to the incoming signal are so strong as to cause both the maximum and minimum peaks of the positive halves of the oscillations to occur **on the flat part of the curve beyond the saturation point of the valve**, then no sound will be produced in the telephones, because under these conditions there can be no change in the current flowing through them.

If the local generator is too powerful, this can easily be corrected and normal conditions restored, but if the effect is brought about by some powerful continuous wave transmitter, which may be not the one which it is desired to receive, then there is no remedy and the result will be a complete wipe out of all signals so long as that station is working.

#### SELF-HETERODYNE METHOD OF RECEPTION

418. In paragraph 400 we pointed out that it was not necessary to have both the grid and sheath circuits of the valve "tuned" for the production of continuous oscillations. We also pointed out in paragraph 404 that even if the normal grid potential of the valve were adjusted to the bend of the curve, reaction between the grid circuit and the sheath circuit would still take place if the coupling between the two were suitably adjusted, although the current pulses in the reaction coil were unidirectional.

419. It will be seen, therefore, that if in the single

circuit receiver illustrated in Fig. 97, the coupling between the reaction coil and the aerial circuit is increased sufficiently, the valve will reach the oscillating condition and **continuous oscillations will be set up in the aerial**. It is also evident that if under these conditions the normal grid potential is adjusted to the bend of the curve, **a rectified current of uniform value will flow through the telephone transformer** and cause no sound in the telephones. It is also clear that the conditions obtaining in the circuits of the receiver in these circumstances are exactly the same as those described in paragraph 411, when an independent high-frequency generator was used to generate oscillations in the aerial. There is this difference between the two cases, however, that whereas formerly the frequency of the oscillations generated was independent of the tuning of the aerial, in the case under consideration it is **only possible to vary the frequency of the local oscillations by varying the tuning of the aerial**. In fact, the oscillations generated will always have exactly the same wave-length as that to which the aerial is tuned.

420. Suppose, then, that it is desired to receive continuous wave signals of a certain wave-length. If we tune the aerial exactly to this wave-length we shall get the maximum resonance effect generated in the aerial by the incoming signals (*vide* chapter on tuning), but on the other hand the oscillations which are already being generated in the aerial by the valve will have exactly the same frequency as those generated by the incoming signal, with the result that the rectified current flowing through the sheath circuit will merely increase or decrease according to what the phase relation between the two happens to be, and will otherwise

remain constant. Thus no sound will be produced in the telephones beyond the click due to the initial alteration in the value of the current. **If, however, we slightly mistune the aerial to the incoming signal**, then the two sets of oscillations will have different frequencies, with the result that beats will be produced, and the current in the sheath circuit will vary at the beat frequency, and thus produce a musical note in the telephones, whose pitch can be adjusted by the amount the aerial is mistuned to the incoming signal.

421. Owing to the mistuning of the aerial, the strength of the oscillations generated in the aerial by the incoming signal will be somewhat reduced, as we are working away from the peak in the resonance curve. The simplicity of this method, however, and the fact that by a single adjustment we can search over a very long range of wave-lengths, makes up in a very large measure for any loss in efficiency.

422. It will be found by applying the formula  $N = n_1 - n_2$  (*vide* paragraph 56) that the number of cycles per second by which the aerial must be mistuned to produce a certain pitch of note is constant, and therefore the percentage by which it must be mistuned will be inversely proportional to the frequency of the wave received. So that **the longer the received wave the more inefficient does the self-heterodyne method become.** On the other hand, when comparatively short wave-lengths are being received, the small amount by which the aerial must be mistuned makes no appreciable difference to the efficiency of reception.

## THE APPLICATION OF THE THREE-ELECTRODE VALVE TO TRANSMITTERS

423. WHETHER the three-electrode valve be used for the purpose of receiving or transmitting aether wave signals, the principles underlying its action remain the same. It is therefore only necessary to discuss in this chapter the question of how these principles should be applied to produce continuous oscillations in an aerial in the simplest and most efficient way.

### DIRECT EXCITATION OF AERIAL

424. In paragraph 419 we showed that continuous or undamped oscillations could be produced in the aerial circuit of a receiver by suitably coupling the reaction coil of the sheath circuit to the aerial. It will be seen at once that such a receiver is actually radiating undamped waves from the aerial to which it is connected, and if we provide some means of interrupting or "keying" the circuits, it could be used as a continuous wave transmitter. This could be accomplished by replacing the telephone transformer in the sheath circuit by an ordinary manipulating key (see Fig. 101), but the efficiency of the system would be small, because the energy in the sheath circuit, which, as we have seen, is large

compared with that in the grid circuit, would, except for the small quantity transferred to the grid circuit, be wasted in heating up the reaction coil and the valve itself.

425. It is obvious that if we reverse the connections of the grid and the sheath by connecting the sheath to the aerial and the grid to the manipulating key and reaction coil, as shown in Fig. 102, we should not only generate oscillations of a far greater amplitude in the aerial, but we should be wast-

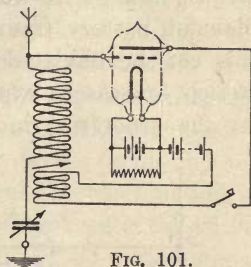


FIG. 101.

ing very little energy in the manipulating key circuit.

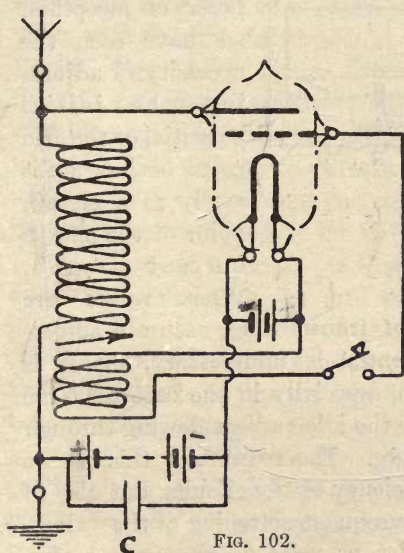


FIG. 102.

426. This is essentially the circuit of the simplest form of valve transmitter, though there are certain modifications which are found expedient in practice. For example, it will be noted that while the positive end of the high-tension battery or generator is connected to

earth, the negative end is connected to the filament battery. As a consequence the full potential of the



high-tension battery would be acting between the filament battery and earth, and therefore, to prevent serious leakage, it would be necessary to insulate the filament battery from the ground. The necessity for this can be obviated by connecting the condenser C (which, for reasons explained in paragraph 349, is shunting the generator) in series with the aerial, as shown in Fig. 103.

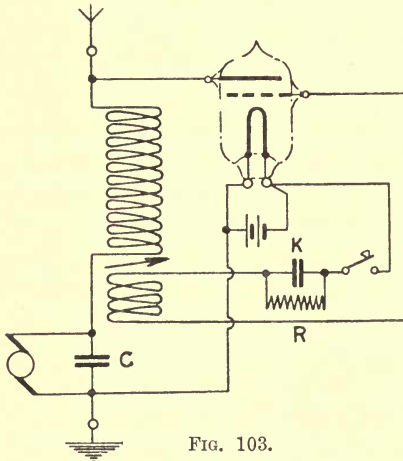


FIG. 103.

427. In previous chapters, when discussing the application of the valve to the various purposes of reception, we have seen the necessity of adjusting the initial potential of the grid more or less accurately to a certain point of the sheath current curve.

**When valves are used for the purpose of transmitting, accurate adjustment of the grid potential is unnecessary,** but it is always necessary, more especially in the case of large power valves, to reduce the idle current flowing through the valve to a minimum. The reason for this is not only to improve the efficiency of the circuits, but also to prevent heating and consequent softening of the valve.

428. For example, let us refer to the curves of a small power transmitting valve illustrated in Fig. 61. It will be observed that if the grid potential is zero

value to the negative end of the filament and the sheath potential is 1500 volts, a current of some 23 milliamperes would flow through the valve. It is easy to see that if the valve is connected up as shown in Fig. 102, when the key is pressed the normal potential of the grid becomes zero, because it is directly connected through the reaction coil to the negative end of the filament.

429. If the valve immediately starts oscillating no particular harm will be done, but if the reaction coil is too loosely coupled, or if for any other reason the valve does not oscillate, a steady current of 23 milliamperes will flow through the valve without doing any work on the external circuits. The consequence of this, as we shall show later, will be to cause excessive heating of the valve with detrimental results.

430. We could, of course, connect a potentiometer in the grid circuit to enable us to adjust the potential to a suitable negative value, but in the case under consideration with 1500 volts on the sheath we would require -12 volts to reduce the normal current to zero, which would require a separate battery for the purpose.

431. There is no need for this if we connect a **condenser in series with the grid circuit** as shown by K in Fig. 103. The effect of this condenser is to insulate the grid from the filament, with the result that the latter, for reasons explained in paragraph 236, becomes charged negatively until its potential is sufficient to stop all flow of current through the valve. Since the condenser is connected between the grid and the filament, it is easy to see that it must also become charged to the same value.

432. It is not desirable in practice, however, to bring the potential of the grid to the point where

no current flows through the valve, as difficulty would be experienced in keying, and, moreover, the oscillations would gradually increase this negative potential in the manner explained in paragraphs 292 to 295. To prevent this, **a leak must be connected across it** as shown by R in Fig. 103, whose resistance must be such as to maintain the grid potential at approximately the best value for efficient working. It will be observed that the value of the grid potential can be approximately regulated by the value of this resistance.

433. In this form of circuit it is apparent that the frequency of the oscillations generated by the valve will always be that of the aerial circuit to which it is connected. The frequency, and therefore the wave-length, of the aerial circuit is governed by the dimensions of the aerial, and the inductance of the aerial tuning inductance. Consequently, the system can very easily be tuned to any desired wave-length, within reasonable limits, by a single adjustment of the aerial tuning inductance.

### POWER OF TRANSMITTING VALVES

434. We have not yet touched upon the question of the limitations to the amount of power that can be carried by a given valve. Power, as we know, is the product of the current and the E.M.F. The current which can pass through the valve is limited by the electron emission from the filament, so that with a given valve only a definite amount of current, which we will call the "maximum valve current," can be used to energise the inductance of the oscillatory circuit.

435. Since the sheath potential is only acting across

the inductance during the positive half of each grid oscillation, and since these oscillations are occurring at the same frequency as the aerial oscillations, **the current flowing through the inductance has only a very short time during which to grow.** The rate of growth in the current flowing through a given inductance is proportional to the E.M.F. applied. In the case we are considering the value of the inductance and the length of time that the current can grow are fixed by the wavelength, and since the maximum value which the current can ever attain is also limited by the particular valve being used, it is obvious that **only a limited E.M.F. can be usefully employed.**

436. To sum up, we may say that in order to force the maximum valve current through a given inductance in such a limited length of time as the frequency of the oscillations permits, we must use a certain sheath potential, but any excess of potential, above what is necessary for this purpose, is obviously wasted. Thus it will be seen that **the limit of useful power which can be carried by a particular valve to a given circuit is the product of the maximum valve current and the potential necessary to force this current through the inductance of that circuit in half the natural time period of the circuit.**

437. If we increase the value of the inductance in the oscillatory circuit, obviously we increase the E.M.F. necessary to force the same current through it in the same length of time, and thus apparently increase the useful power carried by the valve. **But if we increase the inductance of an oscillatory circuit we increase its natural time period,** and thus automatically increase the length of time available for forcing the maximum valve current through it. It will be found, therefore,

that the same E.M.F. as before will be sufficient to force the maximum valve current through the larger inductance, and therefore the useful power carried by the valve remains unaltered.

438. Suppose, however, that we reduce the capacity of the oscillatory circuit in the same ratio as we increase its inductance, **thus keeping its natural time period constant.** In this case it is evident that the increased inductance of the circuit enables us to use a higher potential on the sheath to obtain the maximum valve current through it, thus increasing the useful power carried by the valve. The extent to which the capacity of the oscillatory circuit can be reduced in practice, however, is limited by the self-capacity of the inductive winding, so that **the useful power which can be carried by a given valve is obviously limited by the size of the filament.**

439. The larger the filament the greater is the maximum current which can be forced through the inductance of the oscillatory circuit, and therefore the greater the E.M.F. required to force this current through a given inductance of a circuit having a given time period. The power of the valve is thus increased in two directions, *i.e.* by the greater value of current and the greater value of E.M.F.

It is also evident that, **up to the limits of the current-carrying capacity of a valve, the greater the potential applied to the valve the greater will be the energy given to the oscillatory circuit.**

440. A point which perhaps requires some explanation is that the average value of the current flowing in the oscillatory circuit bears no relation to the value of what is usually termed the "feed current," namely, that



flowing from the high-tension battery or generator through the valve. If there were no loss of energy in the oscillatory circuit each current impulse received from the high-tension battery would increase the amplitude of the current oscillations, so that in time we should get an enormous current flowing backwards and forwards in the oscillatory circuit although the current impulses given to it remain uniformly small. Since there is a loss of energy in the oscillatory circuit, and since the energy lost increases in proportion to the square of the current flowing, the current oscillations increase only until the energy lost during each cycle exactly balances the energy gained. The power represented by the value of the feed current and the voltage at which it is supplied (*i.e.* the potential of the sheath battery) is thus **equal to the power expended in the oscillatory circuit**, but bears no direct relation to the reserve of energy in that circuit.

441. We said that the amplitude of the current oscillations increases until the energy lost during each cycle exactly balances the energy gained. Assuming that the energy gained per cycle is a fixed quantity, then it is evident that the amplitude of the current oscillations when the balance is reached depends upon the effective resistance of the oscillatory circuit. This effective resistance is the sum of the damping due to the ohmic resistance of the windings and that due to radiation of electric waves. Thus, if we take two oscillatory circuits, both of which have the same ohmic resistance, but one of which radiates electric waves to a greater extent than the other, the effective resistance of the good radiator is greater than that of the bad radiator. It is clear, therefore, that for a given quantity

of energy supplied per cycle, and assuming that the time period of the two circuits is the same, the current oscillations will reach a greater amplitude in the circuit which is a bad radiator than they will in the circuit which is a good radiator.

For this reason, the student is warned against taking the value of the current flowing in an oscillatory circuit as an indication of the efficiency of a valve, unless the constants of the circuit are known.

#### GENERATION OF NECESSARY SHEATH POTENTIAL

442. As we have shown, the power which can be carried by a valve is governed by the electron emission, *i.e.* by the size of the filament. But assuming that the filament is large enough to supply all the electrons wanted, we can only use them by applying a sufficiently high potential to the sheath to force the current through the inductive windings of the sheath circuit in the limited time available. To take a practical example, a certain  $\frac{1}{2}$  kw. valve when connected to suitable circuits requires an E.M.F. of 10,000 volts to get the full power through the valve.

443. The design of a D.C. dynamo to generate such a high pressure offers considerable practical difficulties, and the machine would be extremely expensive to manufacture. A much cheaper and in many ways more convenient method is to generate A.C. at a comparatively low pressure, to transform this to the required value by a step-up transformer, and then to rectify the high-tension alternating current and convert it into continuous current by using an ordinary Fleming Valve in conjunction with large reservoir condensers.

444. The connections of a transmitter arranged on these lines are shown diagrammatically in Fig. 104, but this arrangement has the obvious disadvantage of throwing the full transformer potential between the Fleming Valve filament battery and earth, necessitating high insulation between the battery and earth, and also necessitating a separate battery for the filaments of the two valves.

445. The difficulty can be overcome, however, and the filament batteries entirely dispensed with by illumin-

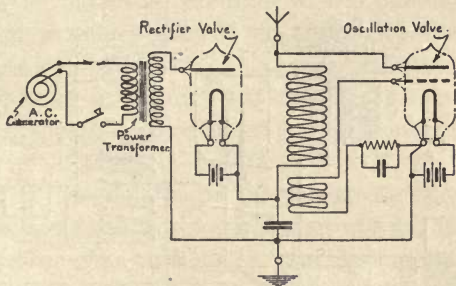


FIG. 104.

ating the filaments of both valves from the A.C. generator, using step-down transformers to bring the E.M.F. to a suitable value for the filaments. A separate transformer winding must, of course, be used for each valve on account of the high insulation necessary between the Fleming Valve filament and earth. The diagram of connections of the transmitter would then be as shown in Fig. 105.

#### EXCESSIVE HEATING OF VALVES

446. A question which will probably occur to most students is, what becomes of the extra power if a higher potential than can usefully be employed on the circuit

is applied to the sheath? Obviously, the surplus energy cannot be absorbed in the external circuit, and must therefore be expended inside the valve itself. We may say at once that the energy is expended in bombarding the sheath with electrons, which strike the sheath with such force as to produce intense heating of the plate.

447. The explanation will be more easily seen by first taking an analogous mechanical example. If we

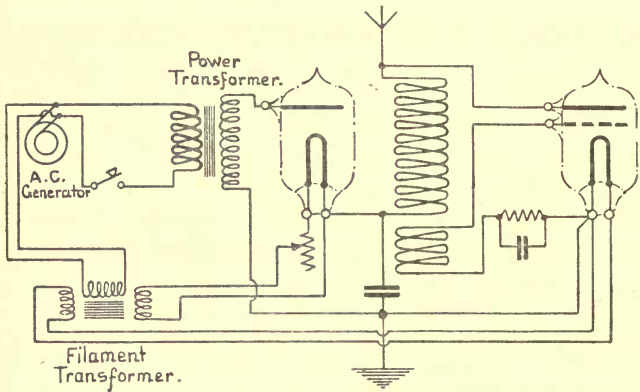


FIG. 105.

hammer a nail into a piece of wood, the energy imparted by each blow of the hammer is used in piercing the wood, and although the energy is eventually all converted into heat, so long as the nail is actually driven through the wood the heat is distributed partly along the length of the nail as it forces its way through the wood, partly in the wood itself, and partly in the head of the nail which receives the impact from the hammer. If, however, the passage of the nail through the wood is obstructed in any way, then the result of striking is to

heat up the head of the nail, which very soon may get too hot to touch.

448. An almost exactly similar thing takes place in the sheath circuit of a valve. Each electron has a certain mass and travels at a certain speed depending upon the E.M.F. to which the sheath is charged, so that we can regard the electrons as delivering small hammer blows to the stationary electrons in the sheath circuit. Up to a certain point the energy given to the filament electrons is used in driving the other electrons through the inductive windings of the circuit, so that, instead of stopping dead at the surface of the sheath, the electrons, by reason of the displacement of the other electrons in the external circuit, are able to penetrate the sheath surface slightly. Although a certain amount of heating is produced where the electrons impinge on the sheath, by far the greater part of the energy is passed on to the other electrons in the external circuit, where some of it is used up in heating the windings of the circuit, and the rest in overcoming the damping due to the radiation of electric waves.

449. The circuit, as we have seen, is only capable of absorbing a definite amount of energy from each electron. The energy stored up in an electron is the product of its mass, which is constant, and its speed, so that any excessive speed given to it by the sheath potential beyond what is required, *i.e.* beyond what can be absorbed by the other electrons in the circuit, simply causes it to strike the sheath harder without driving the other electrons any further along the external circuit. The result, as we pointed out, is to cause heating of the sheath, which, if the excessive pressure be carried far enough, will actually make the sheath red-hot, or even white-hot.



450. To return to our mechanical analogy, similar conditions could be arranged by placing some obstruction, such as a piece of iron, behind the wood so that when the nail has penetrated the wood its progress is stopped by the piece of iron. It is clear, then, that so long as the energy imparted to it by a blow from a hammer is not more than sufficient to make it completely penetrate the wood, there will be no undue heating of the head of the nail. Any energy imparted to it by the hammer in excess of the amount necessary, will not produce any further movement of the nail, but, as already noted, will generate heat at the nail head.

451. Now the amount of energy imparted to the nail by the hammer is proportional to the mass of the hammer and the square of the velocity at which it is travelling when it strikes, just as the energy imparted to the electrons in the sheath circuit by the electron drawn from the filament to the sheath is proportional to the mass of the electron and the square of the velocity it has attained when it strikes the sheath. Also, the amount of energy which can be absorbed by the nail before it reaches the obstruction depends upon the nature of the material it has to penetrate, *i.e.* its toughness, etc., just as the amount of energy which can be absorbed by the electrons in the sheath circuit depends upon the nature of the circuit, *i.e.* its resistance, etc.

452. It is clear, therefore, that if the toughness of the material is such as to allow not more than complete penetration by the nail for a given hammer blow, no undue heating will be generated at the head of the nail, but if the material be so fragile as to offer very little resistance, then the same hammer blow will expend only a small part of its energy in forcing the nail through the

material, and the rest will be expended in generating heat at the nail head.

453. In order to see clearly how this analogy applies to the valve circuit we can imagine the external sheath circuit to consist of a tube of electrons, as shown in Fig. 106. The end Y represents the surface of the sheath and the end X represents the filament. The gap between X and Y thus represents the vacuum inside the bulb. Suppose, then, that the size and temperature of the filament at X is such as to liberate only one electron A. When that electron is liberated from X it leaves a gap which will allow all the other electrons to be moved on exactly one step to fill the gap, but having filled the gap they come to a dead stop.

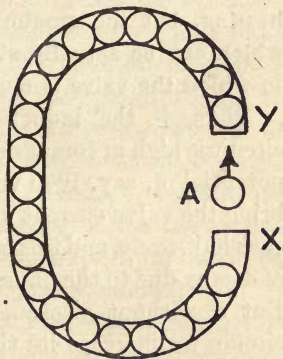


FIG. 106.

454. If the friction in the tube is such that the velocity attained by A when it arrives at Y (this velocity depending upon the E.M.F. applied between X and Y) is not more than sufficient to drive the other electrons through the tube and just fill the gap, no undue heating will be generated at Y, as the expenditure of energy will be distributed all along the tube; but if, on the other hand, the friction in the tube is very small, then only part of the energy given to A will be expended along the tube, and the rest will be used in generating heat at Y.

In this analogy we have for the sake of simplicity taken no consideration of the factor of inertia or

inductance and confined ourselves purely to friction or resistance. The analogy holds perfectly true, however, if we take the inertia of the electrons in the tube to represent the inductance of the sheath circuit, and the rate at which the electrons are displaced to represent the current flowing.

455. **An important point to notice is that it is not the total amount of E.M.F. used that causes this excessive heating, but the amount of pressure in excess of that which can be actually absorbed by the particular circuit to which the valve is applied.**

Thus, if the inductance of the sheath oscillatory circuit is high in comparison with its time period, a sheath potential of, say, 1000 volts may be only just enough to bring the valve current up to the saturation point during each half-cycle, and therefore there will be no undue waste of energy due to the impact of the electrons on the sheath. But if without altering the inductance of the sheath circuit we increase its time period, or, to take it to an extreme, if we maintain the positive grid potential at a steady value for an unlimited time by substituting a suitable potentiometer for the reaction coil, then although for the first fraction of a second while the current is growing the full 1000 volts is absorbed in the external circuit, as soon as the current reaches its maximum value (as limited by the electron emission) practically the whole of the 1000 volts is wasted in heating up the sheath, because after reaching this value only a very small sheath potential (depending upon the resistance of the circuit) is necessary to maintain the current.

456. It is for this reason that if a steady current is allowed to pass through a valve by maintaining the grid

potential at a suitable value, the sheath of the valve may become excessively hot, **although the same valve remains comparatively cool when a far greater current is passed through it under working conditions.**

### SOFTENING OF VALVES

457. Having examined possible causes for excessive heating of the sheath, let us see what effect it may have on the working of the valve. The most obvious effect is a reduction in the efficiency of the system, that is to say, in the case of a transmitting valve a reduction in the ratio between the power radiated in electric waves to the power expended on the circuits. Quite apart from this, however, **excessive heating of the sheath has a very detrimental effect on the valve itself, inasmuch as it may destroy or partially destroy the vacuum.**

458. The reason for this is that a certain amount of gas is locked up in the metal of which the sheath is made, and some of this gas is liberated when the metal is heated in a vacuum. The higher the temperature to which the metal is heated, the greater the quantity of gas liberated from its surface.

459. The gas, as soon as it is liberated, diffuses throughout the vacuum, with the result that **the space inside the bulb becomes charged with atoms.** The effect on the characteristics of the valve is very complex, and no useful purpose will be served in this book by examining them in too much detail. It will be sufficient for our purpose if we point out in a general way what happens.

460. The speed at which an electron travels follows exactly the same laws as a body falling through space,

that is to say, its speed increases with time, assuming that the force attracting it remains constant.

The force attracting the electrons from the filament is the potential or E.M.F. of the sheath, so that the electrons in the valve start off from the filament and attain a higher and higher velocity until they arrive at the sheath. But if the space through which they travel is charged more or less with immobile atoms, some of the electrons collide with these atoms before they get to the sheath.

461. Now an atom is many thousands of times bigger than an electron (*vide* paragraph 116), so that the result of a collision is to at least retard the progress of the electron. The precise result depends largely upon the speed at which the electron is travelling when it hits the atom, but, generally speaking, it knocks off one or more electrons from the atom.

462. An atom with a deficiency of electrons becomes a positive ion and will be attracted to a negatively charged body; thus, after the collision the ion is attracted by, and falls on, the negatively charged filament or grid. The electrons which were knocked off it, however, being negative, are attracted to the positively charged sheath, so that for every electron that leaves the filament two or more will arrive at the sheath.

463. So far as the sheath circuit is concerned, it will be seen that **we get an increased current flowing through the valve for a given electron emission from the filament**, but since at the same time the velocity of the electrons is greatly reduced, there is no gain in energy.

464. So far as the grid circuit is concerned, it will be seen that assuming the positive ions fall on to the grid, they will more or less (according to their number)



neutralise the current in the grid circuit due to the flow of negative electrons from the filament to the grid, and if their number be sufficient, not only will they neutralise all of this current, but actually cause a current to flow in the reverse direction through the grid circuit.

465. This brief explanation is sufficient to show that any serious "softening" of the valve will entirely upset its characteristics and action, and will render it useless for the purposes described, at all events unless this condition is specially arranged for in the design of the circuits to which it is applied.

466. To prevent the softening of a valve, or rather to reduce it as far as possible, special precautions are taken in the "pumping" of valves during the process of manufacture. Arrangements are made for heating the sheath to a high temperature at the same time that the bulb is being exhausted. In some cases the sheath is formed by a metal spiral both ends of which are brought through the glass bulb; the temperature of the spiral can then be raised to any desired degree by passing a current through it. This method is for obvious reasons impracticable in the case of cylindrical sheaths, and the method then resorted to is to bombard the sheath with electrons. This can be done by rendering the filament incandescent and applying a high potential to the sheath. Cost of production limits the extent to which either process can be carried.

467. There are several indications which enable one to tell when a valve is going "soft." The first is loss of power in the oscillatory circuit, indicated by a reduction in the aerial current. Another is "creeping" of the feed current. This can only be noticed when a milliamperemeter is connected in series with the high-tension

battery or generator. When a valve is soft the current flowing through it will slowly increase or creep as the ionisation of the liberated gas increases. This increased current still further increases the temperature inside the bulb and thus liberates more and more gas. Yet another indication is **a blue glow like a brush discharge inside the bulb** between the filament and the sheath. This is produced by the energy expended by the electrons as they collide with the atoms, and if noticeable is a certain indication of the softness of a valve.

#### INDIRECT EXCITATION OF AERIAL

468. The transmitters which we have illustrated diagrammatically up to the present have all been of the single tuned circuit type, in which the aerial circuit is directly energised by the valve. As a result the length of the wave radiated is always that of the aerial circuit. This has the great advantage of simplicity and efficiency, but in some circumstances there are certain disadvantages. Chief amongst these are (1) the impracticability of exactly calibrating the circuit for wave-lengths unless used with a fixed and always constant aerial system; (2) the difficulty of "keying" the grid circuit sometimes experienced with power valves of  $\frac{1}{2}$  kw. and upwards; (3) the possibility of radiating harmonics of the fundamental wave.

469. The first of these disadvantages is more noticeable in the case of portable and aeroplane transmitting sets, where the aerial wire itself may vary considerably in length and environment without being noticed, so that an operator might quite easily be working on a very different wave-length from what is intended.

The only way he could find out would be to measure the wave-length with a wave-meter, an operation of some difficulty in an aeroplane.

470. The simplest way of overcoming this difficulty is to use a coupled circuit transmitter, as shown in Fig. 107. This enables the tuned circuit S, which is directly energised by the valve and is exactly calibrated for wave-lengths, to be set to the wave-length it is desired to transmit, while the aerial circuit can be adjusted to resonance, the tuning point being noted when a current-measuring instrument such as A, Fig. 107, indicates the maximum aerial current.

471. For large power valves the method illustrated in Fig. 108 is sometimes used, as this gets over the difficulty of keying which, as already mentioned, is sometimes experienced with power valves. It also provides a tuned circuit which can be calibrated.

The action of this transmitter is similar to that of the high-frequency magnifier described in paragraphs 345 to 359. The valve  $V_1$  can be a comparatively low power valve capable of carrying some twenty watts or so, and is used to energise the tuned and calibrated oscillatory circuit P. This circuit is closely coupled to the grid circuit of the power valve  $V_2$  which is used to

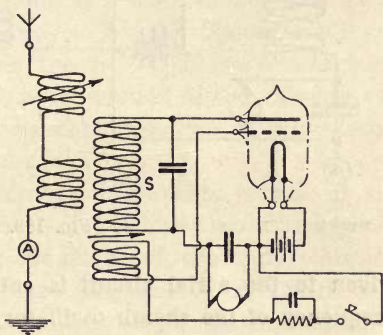


FIG. 107.

energise the aerial. Since there is no reaction between the aerial circuit and the grid circuits of either of the valves, it is evident that the frequency of the impulses

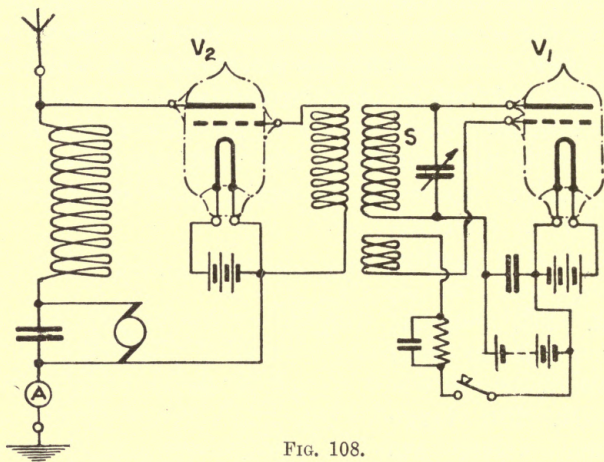


FIG. 108.

given to the aerial circuit is entirely governed by the frequency of the sheath oscillatory circuit S of the first valve. Thus, if this circuit is calibrated and is set to the wave-length it is desired to transmit, the aerial can be tuned to resonance in the ordinary way.



## THE THEORY OF THE SOFT VALVE

472. WE explained briefly in paragraphs 457 to 464 some of the effects produced if the vacuum in a valve becomes partially destroyed by the liberation of gas from the metal inside the bulb. These effects have been made use of in the application of the valve to the purposes of reception in what is known as the "soft" valve.

Owing to the critical and unstable nature of the conditions which are necessary to give the desired result, and owing to the development of the high-frequency magnifier, the soft valve has fallen very much into disuse, but it has undeniable advantages in sensitiveness when the conditions inside the bulb are just right. In any case a brief explanation of the theory of its action may be of some interest to the reader.

473. In paragraph 464 we mentioned that the fall of the positive ions on the grid tended to reduce and even reverse the direction of the current in the grid circuit due to the flow of negative electrons from the filament to the grid. The extent to which this takes place depends largely upon the degree to which the valve is softened, the velocity of the electrons, and whether the ionisation of the gas takes place between the filament and the grid or between the grid and the



sheath. If the characteristic grid and sheath current curves be plotted when the softness of the valve is just right, they will take approximately the form shown in Fig. 109.

474. Taking first the grid current curve, it will be noticed that between the points X and Y the current

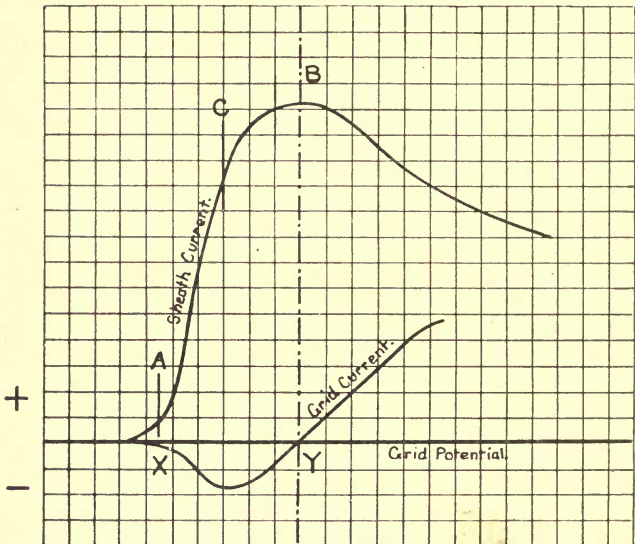


FIG. 109.

in the grid circuit rises to a maximum value in the opposite direction to the sheath current and then falls to zero. This, as already explained, is due to the fall of the positive ions on to the grid which neutralise and reverse the current due to the negative electrons. After the point Y is reached the grid becomes more and more positive to the filament, and therefore not only are a

greater number of negative electrons attracted to the grid, but also fewer ions fall on the grid, on account of the fact that **the ionisation of the gas takes place to a greater extent between the filament and the grid**, and the ions therefore fall on the filament instead of on to the grid; the result is that the grid current increases very rapidly.

475. If we examine the sheath current curve we find that up to the point C the current increases very rapidly. This is partly accounted for by the reduction of the shielding effect of the grid and partly by the increased number of electrons liberated by ionisation. After the point Y the current in the sheath circuit rapidly falls off, owing to the fact that fewer electrons get past the positive grid and that the ionisation of the gas between the grid and the sheath is thereby reduced.

476. The principle of the application of a valve having these characteristics, to the circuits of a receiver, are much the same as that of the hard valve except that **a different point on the curve is chosen for rectification.**

477. The bend of the curve at A is very much the same as that of a hard valve, and if the initial potential of the grid be adjusted to this point the efficiency of rectification of the soft valve will be found to be much the same as that of the hard valve.

478. The sharpness of the bend in the curve at the point B is also very much the same as at the point A, but there is this difference. At the point A an increase in the potential causes an increase in the current, and a decrease in the potential causes a decrease in the current, with the result, as we showed in paragraphs 171 to 176, that the effective value of the rectified current is **the difference between the increase and decrease due to the positive and negative impulses applied to the grid.** At

the point B, on the other hand, both an increase and a decrease in the potential of the grid cause a decrease in the current, with the result that the effective value of the rectified current, if the initial grid potential be adjusted to this point, is the sum of the two variations.

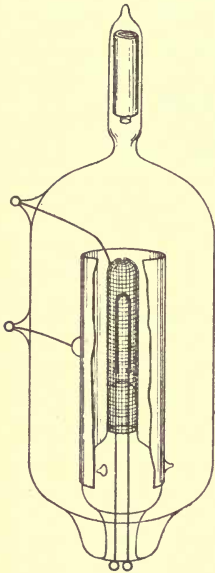


FIG. 110.

The valve also shows an advantage as a high-frequency magnifier, because the steepness of the slope of the curve at C is greater than in the ordinary hard valve. This is due to the fact that the flow of electrons is augmented by the ionisation of the gas.

479. To enable the softness of the valve to be regulated to the critical point where approximately these characteristics are obtained, the bulb is extended into a small chamber at the top, as illustrated in Fig. 110. This chamber contains a piece of asbestos, which when heated liberates a certain amount of gas. The tube is first pumped fairly hard and the vacuum afterwards reduced by applying a match to the outside of this chamber.

## INDEX

- Aerial circuit, connection of three-electrode valve to, 114, 187
- Aerial, direct excitation of, 187  
indirect excitation of, 204
- Amplifier, high-frequency, 47, 146  
sensitiveness of, 162-167
- Amplifier, resistance, advantages of, 155  
effect of valve capacity on sensitiveness, 161
- Amplifier, semi-aperiodic, 165  
connections of, 169  
sensitiveness of, 168
- Amplifier, tuned, 148  
disadvantages, 152  
resistance of, 162  
sensitiveness curve of, 156
- Amplitude of E.M.F., effect on rectification efficiency, 70  
of oscillations, effect of reaction on, 174
- Atoms, composition of, 50
- Beat reception, application of, 26  
principles of, 21-33
- Beats, diagrammatic illustration of, 33  
produced by periodic force acting on mistuned circuit, 36, 42  
relation of, to superimposed frequencies, 25
- Brilliance of filament, effect of on current, 62, 88  
effect of on rectification point, 89
- Capacity of grid, 94
- Capacity of high-tension battery, 150
- Characteristic curve, effect of design of valve on, 103-106  
effect of filament temperature on, 62, 89  
method of obtaining, 60  
of Fleming valve, 62  
of three-electrode valve, 85, 107, 109, 112
- Condenser, grid, 119  
grid, application to receivers, 130  
grid, application to valve transmitters, 189  
grid, capacity of, 131  
grid, charging up of, 93, 123  
grid, effect of, on grid potential, 123  
grid, shunting of, 130, 190
- Condenser, reservoir, 8  
reservoir, across high-tension battery, 150
- Conduction of electricity through matter, 52  
through vacuum, 51  
through valves, 59

- Continuous oscillations, generation of by reaction, 173
- Continuous wave signals, production of sound by, 18-32
- Current in grid circuit, 95  
effect of, on sheath current, 100  
effect of, on valve efficiency, 118  
value of, 95, 98, 100
- Current in sheath circuit, value of, 86
- Current through valve, distribution of, 87, 92  
effect of grid potential on, 83
- Curves, resonance, 38, 41, 43
- Curves of valves, typical, 109, 112
- Damped wave signals, use of reaction in reception of, 174  
production of sound by, 17
- Damping, effect of, on resonance curves, 41  
reduction of by reaction, 172
- Design of valve, effect of on characteristics, 105, 106
- Dimensions of filament, 102
- Direct excitation of aerial, 187
- Direction of flow of electricity, 49  
of flow of electrons, 49
- Distribution of electrostatic field in valve, 96-99, 105
- Effective value of rectified current, 69
- Efficiency of rectification, 69, 70, 116  
of ticker, 20
- Electricity, conduction of, by electrons, 50  
conduction of, through matter, 52  
conduction of, through vacuum, 51  
direction of conduction through valve, 59  
direction of flow, 49
- Electron theory, 48-56
- Electrons, attraction of, 54  
direction of flow, 49  
liberation of, 55, 202, 207  
magnitude of, 49  
momentum of, 98  
polarity of, 49
- Electrostatic field, distribution of in valve, 96-99, 105
- E.M.F. magnification by valve, 140
- Energy, absorbed by oscillatory circuit, effect on tuning, 44  
magnification by valve, 141
- Filament, drop of potential along, 75  
purpose of, 58  
size of, 102
- Filament brilliancy, adjustment of, 90
- Fleming valve, application of to receivers, 65  
best adjustment of, 72  
characteristic curve of, 62  
description of, 57  
efficiency of rectification by, 69, 70  
low-frequency rectification by, 80, 194
- Frequencies, superimposed, relation of to beats, 25
- Grid, 82  
capacity of, 94  
effect of insulation of, 93  
regulation of potential, 95, 190  
shunting of, 190
- Grid circuit, current flowing through, 94  
definition of, 84
- Grid condenser, application to receivers, 129  
application to valve transmitters, 189  
capacity of, 131  
charging up of, 93, 123

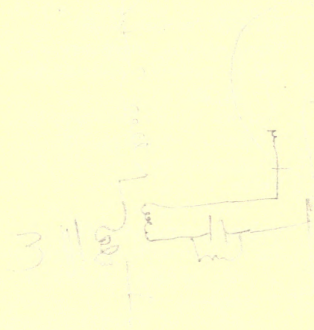


- Grid condenser (*continued*)—  
 method of rectifying by, 119  
 shunt resistance of, 131  
 shunting of, 130, 190
- Grid current, effect of on sheath current, 100  
 effect of on valve efficiency, 118  
 reversal of, 203  
 value of, 95, 98, 100
- Grid mesh, effect of, 103  
 and magnification constant, 108
- Grid potential, adjustment of, 113, 143, 190  
 effect of grid condenser on, 123, 189  
 effect of, on valve current, 83  
 measurement of, 84  
 negative charge on, 94
- Heating of valves, causes of, 195
- Heterodyne reception, application of, 176  
 necessary conditions for, 182  
 sensitiveness of, 182
- High-frequency amplifier, advantages of, 147  
 definition of, 47  
 tuned, 148
- High-frequency oscillation, control of, 205
- High-tension battery, effect of capacity of, 150
- Independent heterodyne reception, 176
- Indirect excitation of aerial, 204
- Insulation of grid, effect of, 93
- Ion, definition of, 53  
 polarity of, 54
- Ionisation in valves, effect on feed current, 201
- Ionisation of gas in valves, 201
- Low-frequency magnifier, definition of, 47
- Magnetism of telephone receiver, 3
- Magnification by valve, limitations of, 135, 145  
 high-frequency, advantages of, 147  
 note-frequency, disadvantages of, 146  
 of E.M.F. by valve, 140  
 of energy by valve, 141  
 of note-frequency, 142  
 of valve current, 140, 202
- Magnification constant and grid mesh, 108
- Magnification constant, calculation of, 107  
 definition of, 106
- Magnifier, high-frequency, 47, 146  
 low-frequency, 47, 141  
 note, 47, 141
- Magnitude of electron, 49
- Matter, nature of, 50
- Mechanical proportions of valve, 101-109
- Note magnification, disadvantages of, 146
- Note magnifier, 142  
 definition of, 47
- Oscillation frequency, control of, 205
- Periodic force, effect on mistuned circuits, 36  
 effect on tuned circuits, 35
- Persistence of oscillation effect of reaction on, 171
- Polarity of electron, 49  
 of ions, 54
- Potential, drop along filament, effect of, 75  
 drop along filament, illustration of, 76  
 effect of excess of, 196  
 sheath, application of, 77, 78
- Potential of grid, adjustment of, 113, 143, 190

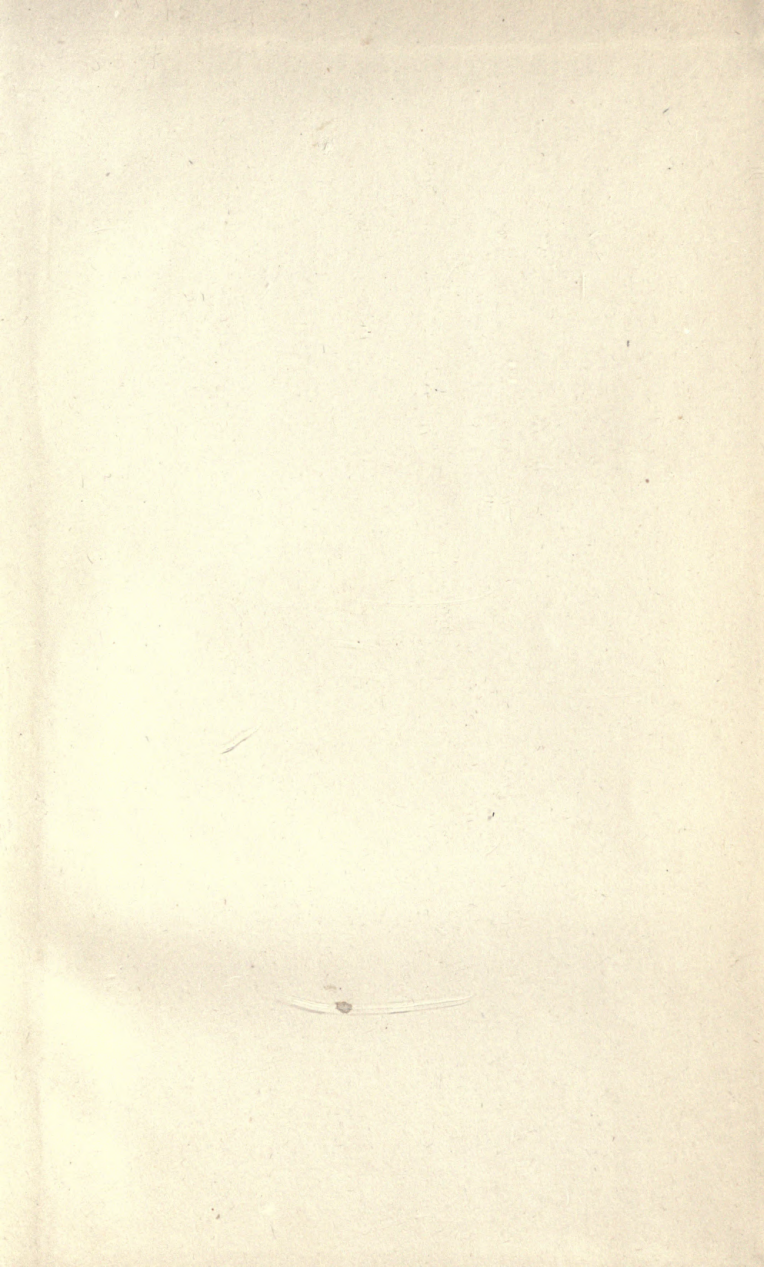
- Potential of grid (*continued*)—  
 effect of on valve current, 83  
 regulation of, 95, 190  
 adjustment of for transmitting valves, 188
- Potential of sheath, 192, 200  
 effect of on valve curve, 90
- Reaction, 170  
 effect of on persistence of oscillations, 171  
 effect on amplitude, 174  
 generation of continuous oscillations by, 173  
 reduction of damping by, 172  
 use of for reception of spark signals, 174
- Reaction receiver, connections of, 175
- Receiver, independent heterodyne, 176  
 self-heterodyne, 183  
 self-heterodyne, inefficiency of, 185  
 telephone, 2
- Receivers, application of Fleming valve to, 65  
 general consideration, 1-45
- Rectification, by three-electrode valves, 90, 111  
 efficiency of three-electrode valve, 116  
 explanation of, 6  
 high-frequency, 146  
 low-frequency, 80
- Rectification efficiency, effect of amplitude of E.M.F. on, 70
- Rectification point, effect of filament brilliancy on, 89
- Rectified current, effective value of, 69  
 uniformity of, 9
- Rectifier, action of, 41, 42  
 definition of, 5, 47
- Relays, limitations of, 134
- Reservoir condenser, 8  
 across high-tension battery, 150
- Reservoir condensers, typical values, 11
- Resistance, of condenser shunt, 131, 190  
 of valve, 138, 140
- Resistance amplifier, advantages of, 155  
 application of, 160  
 effect of capacity on, 161  
 sensitiveness of, 161  
 theory of, 159
- Resonance curve, distortion of, 44  
 effect of damping on, 41  
 theoretical, of undamped circuit, 38
- Resonance curves, 41, 43
- Saturation point, 62
- Self-heterodyne reception, 183  
 inefficiency of, 185
- Semi-aperiodic amplifier, 165  
 connections of, 169  
 sensitiveness of, 168
- Sensitiveness curves, explanation of, 156
- Sensitiveness of heterodyne reception, 182  
 of resistance amplifier, 162  
 of tuned amplifier, 156
- Sheath, 59
- Sheath circuit, definition of, 83
- Sheath current, value of, 86
- Sheath potential, excessive, effect of, 196  
 generation of, 192  
 value of for transmitters, 192
- Soft valve, theory of, 207
- Softening of valves, causes of, 201
- Sound, production by continuous wave signals, 18-32  
 production by damped wave signals, 17

- Telephone receiver, 2  
magnetism of, 3
- Telephone transformer, effect of  
capacity of, 145  
impedance of, 141  
purpose of, 115
- Temperature of filament, ad-  
justment of, 90  
effect on characteristic curve, 62  
effect on current, 88  
effect on rectification point,  
69  
effect on electron emission,  
63
- Three-electrode valve, applica-  
tion of as a rectifier, 111  
adjustment of, 114  
as a rectifier, 90, 111  
characteristic curve of, 85,  
108, 109, 112  
connection to aerial circuit,  
114, 187  
description of, 82  
effect of filament brilliancy on  
current, 88  
rectification efficiency of, 116
- Ticker, application of, 18  
explanation of, 19  
inefficiency of, 20
- Transformer, telephone, effect of  
capacity, 145  
telephone, impedance, 141  
telephone, purpose of, 115
- Transformer windings, effect of  
capacity of, 136
- Transmitting circuits, calibra-  
tion of, 206  
indirect excitation, 204
- Transmitting valve, 186, 206  
effect of excessive sheath  
potential, 196  
limitation of power, 190  
sheath potential of, 192, 200
- Tuned amplifier, disadvantages  
of, 152
- Tuning, curves, 38, 41, 43  
definition of, 34  
sharpness of, 34  
effect of energy absorption on,  
44
- Typical valve curves, 108, 112
- Uniformity of rectified current, 9
- Vacuum, nature of, 50
- Valve circuit, resistance of, 140
- Valve current, distribution of,  
87, 92  
effect of on ionisation, 201  
effect of on valve, 200  
magnification of, 140, 202
- Valve curve, effect of sheath  
potential on, 90
- Valve transmitter, 186
- Valve transmitters, adjustment  
of sheath potential of,  
188  
method of connecting gener-  
ator to, 188
- Valves, effect of ionisation on, 201  
energy magnification of, 141  
limitation of magnification,  
135, 145  
resistance of, 138  
sheath potential of, 200

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